

(NASA-CR-192799) CENTER FOR SPACE  
MICROELECTRONICS TECHNOLOGY  
Technical Report, 1991 (JPL)  
105 p

N93-22812

Unclas

G3/33 0154716

## Center for Space Microelectronics Technology

# 1991 Technical Report



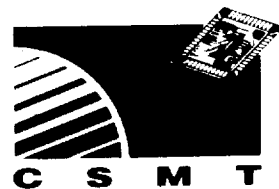
July 1, 1992

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**NASA**

National Aeronautics and  
Space Administration

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California



*Center for Space Microelectronics Technology  
Jet Propulsion Laboratory – May 28, 1992*

*NASA Administrator Daniel Goldin toured the Microdevices Laboratory  
and was given a demonstration of the microseismometer and microrover.  
Bill Kaiser demonstrates the microseismometer to JPL Director Edward  
Stone and Daniel Goldin.*

1. Report No. JPL Pub 92-13	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Center for Space Microelectronics Technology 1991 Technical Report		5. Report Date July 1, 1992	
		6. Performing Organization Code	
7. Author(s) Center for Space Microelectronics Technology		8. Performing Organization Report No.	
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91109		10. Work Unit No.	
		11. Contract or Grant No. NAS7-918	
		13. Type of Report and Period Covered Annual Technical Report	
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract  The 1991 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the Center during the past year. The report lists 193 publications, 211 presentations, and 125 new technology reports and patents.			
17. Key Words (Selected by Author(s)) Neural Networks - Microcircuit Technology - Computer Operations and Hardware - Electronics and Electrical Engineering - Solid State Physics - IR, UV, Optical Detection		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 108	22. Price



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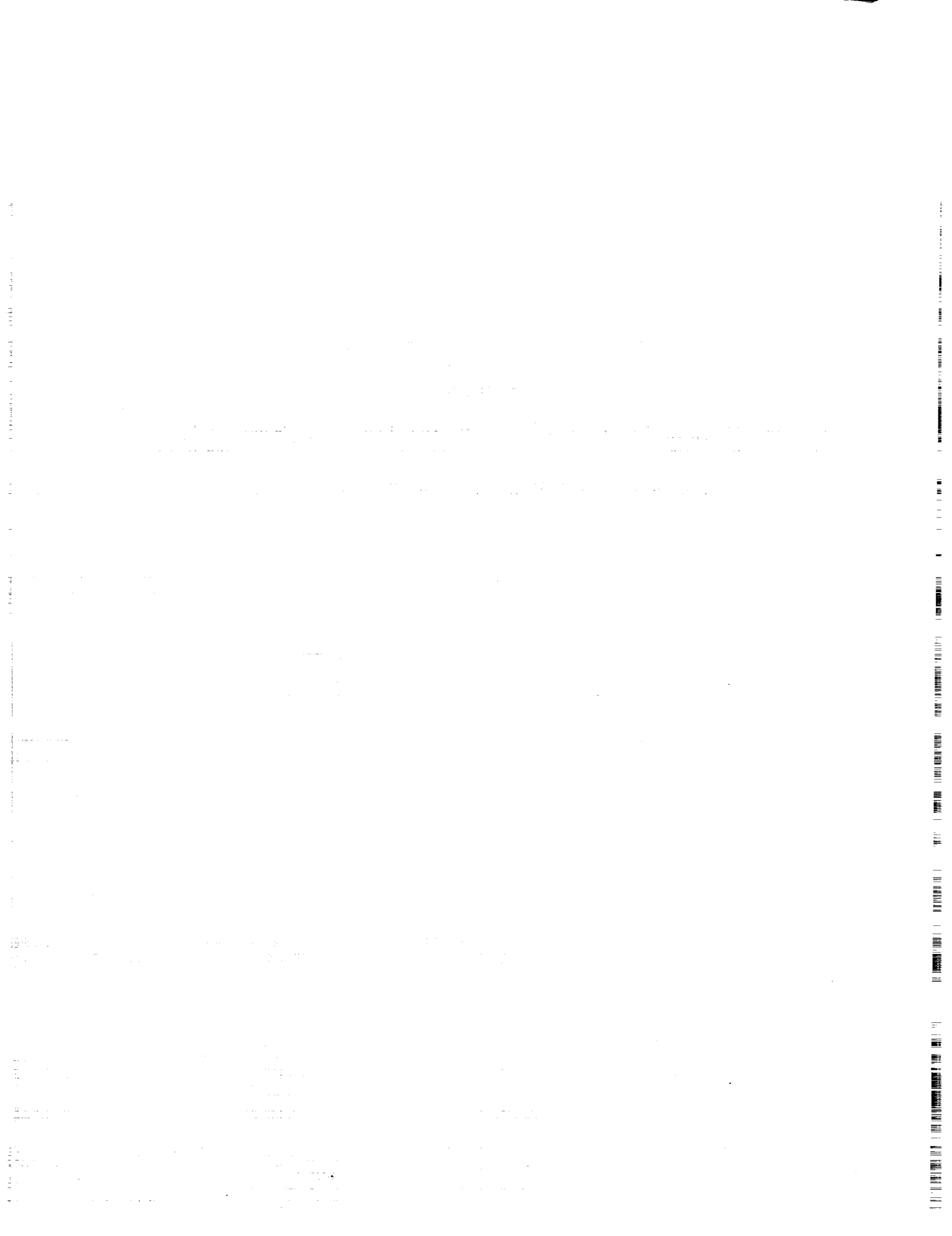
The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration; Strategic Defense Initiative Organization/Innovative Science and Technology Office; Defense Advanced Research Projects Agency; U.S. Army; U.S. Navy; U.S. Air Force; and U.S. Department of Energy.

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## Abstract

The 1991 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the Center during the past year. The report lists 193 publications, 211 presentations, and 125 new technology reports and patents.



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# Director's Report

This report is published on the fifth anniversary of the Center for Space Microelectronics Technology (CSMT), which was founded in 1987 at Caltech's Jet Propulsion Laboratory (JPL). NASA and several Department of Defense (DoD) agencies with space responsibilities established CSMT in order to create a critical mass program in space microelectronics with world-class facilities, equipment and staff.

The Center concentrates on innovative, high-risk, high-payoff concepts and devices with the potential to enable future space missions and to significantly enhance current and planned missions. CSMT conducts research and development in four technical areas: solid-state devices, photonics, custom microcircuits and advanced computing. Research and development are pursued through proof of concept demonstration, and successes are transferred to engineering development at JPL, in other Government laboratories and industry.

CSMT focuses on those aspects of microelectronics and advanced computing that are unique to space applications. A concrete example is the development of new sensors for the very long wavelength infrared and submillimeter regions of the electromagnetic spectrum where the atmosphere is opaque and one must get into space to do observations. Another example is the development of laser systems of specific wavelengths tuned to the absorption lines of trace gases in the Earth's atmosphere.

Space systems require low mass and power consumption with extremely high reliability. CSMT's new thrust in microsensors and microinstruments directly addresses these issues. Custom microcircuits, including electronic neural networks and low temperature sensor readout chips, are major elements of the CSMT miniaturization program.

Analysis of the enormous amount of data generated by modern NASA and DoD space missions requires orders of magnitude increase in computing power, both on the spacecraft and on the ground, and similar improvements in communications rates. To support these requirements, CSMT has aggressive programs in high performance parallel computing, data visualization, optical communications and gigabit networks.

After five years, CSMT has gained national recognition for its efforts in the following areas:

- Electron tunneling.
- Terahertz/submillimeter technology.
- Concurrent (parallel) computing.
- Neural networks.
- Microsensors and microinstruments.
- Silicon-compatible infrared detectors.

CSMT also has significant programs in:

- Long wavelength and far-infrared detectors.
- Low and high temperature superconductors.
- Semiconductor lasers.
- Acousto-optical tunable filter spectrometers.

And, CSMT is investing in these areas for future applications:

- Nanometer devices.
- Optoelectronic integrated circuits.
- Innovative materials.

Policy guidance and program oversight for the Center are provided by the CSMT Board of Governors. Board members are the major sponsors of the Center, together with the Director of JPL and the Caltech President and Provost. This year, the U.S. Army Laboratory Command with responsibility to develop space technology for Army needs became a major sponsor, and Col. David Jackson, Director of the Army Space Technology and Research Office, joined the Board of Governors.

Although CSMT's mission is to perform research and development in space microelectronics for NASA and DoD space missions, several CSMT inventions also have significant commercial potential on Earth. Dr. Robert White, Undersecretary for Technology, U.S. Department of Commerce, has recently joined the Board of Governors to help develop innovative approaches for CSMT to work with industry to enhance U.S. competitiveness. The members of the CSMT Board of Governors are:

- Dr. Edward Stone, (Chairman), Director, JPL.
- Dr. Gary Denman, Director, Defense Advanced Research Projects Agency.
- Dr. Dwight Duston, Director, Strategic Defense Initiative Organization/Innovative Science and Technology Office.
- Dr. Thomas Everhart, President, Caltech.
- Dr. Lennard Fisk, Associate Administrator, Office of Space Science and Applications, NASA.
- Col. David Jackson, Director, Army Space Technology and Research Office.
- Dr. Paul Jennings, Vice President and Provost, Caltech.
- Mr. Richard Petersen, Associate Administrator, Office of Aeronautics and Space Technology, NASA.
- Dr. Robert White, Undersecretary for Technology, U.S. Department of Commerce.

The CSMT Scientific Advisory Board, comprising seven world-renowned scientists, reviews the technical program and provides advice to the Board of Governors and CSMT Director. The remainder of this Director's Report summarizes last year's achievements on the technical, programmatic and institutional fronts.

## Technical Highlights

CSMT has a number of technical achievements to report. CSMT scientists and engineers accomplished the following:

- *Long-Wavelength Infrared Detectors.* Fabricated  $128 \times 128$  arrays of  $\text{Si}_x\text{Ge}_{1-x}/\text{Si}$  heterojunction internal photoemission infrared detectors; demonstrated 5 percent quantum efficiency in the 8–12 micron range and a cutoff wavelength of approximately 18 microns.
- *Electron Tunnel Sensors.* Demonstrated operation of a prototype electron tunneling infrared sensor with the following unique features: uncooled broadband sensor (1–1000 microns); 10 times more sensitive than a pyroelectric detector; silicon micromachining used to fabricate all sensor components; array-compatible.
- *Long Duration Exposure Facility.* Explained and documented radiation darkening, temperature effects and connector contamination on fiber samples carried on the Long Duration Exposure Facility (LDEF), which was launched in 1985 and recovered in 1990. The sample suffered less than 4 decibels loss per kilometer, and the results strongly support the use of fiber optics in space.
- *Semiconductor Lasers.* Demonstrated a CW single-mode 727-nanometer diode laser for injection locking of a solid-state laser.
- *Combined Release and Radiation Effects Satellite (CRRES).* A CSMT radiation effects test chip was carried aboard CRRES, which was launched in 1990.
- *Submillimeter Sensor Technology.* Demonstrated a niobium superconductor-insulator-superconductor tunnel junction at 500 gigahertz in a Caltech waveguide mixer; demonstrated a 490-gigahertz system consisting of quasi-optical lens, SIS mixer and a quintupled Gunn local oscillator.
- *High Temperature Superconductivity.* Successfully fabricated a YBaCuO superconducting-normal metal-superconducting (SNS) weak link operating at 87 kelvins.
- *Optically Addressed Spatial Light Modulator (O-SLM).* Fabricated asymmetric Fabry-Perot O-SLM structures with npn/multiple quantum-well active material; demonstrated record-breaking, high-contrast (greater than 60:1) modulation performance with only a 30-milliwatt laser diode source.
- *Sensor Electronics.* Demonstrated a low noise, two-dimensional electron gas FET sensor readout device operating at 5 kelvins.

- *Electronic Neural Networks.* Transferred the neuroprocessing chip technology to McDonnell Douglas Corporation and Charles Stark Draper Laboratory; developed a neural-network inspired, dedicated processor that solves the computation-intensive "route-planning" problem at ultrahigh speeds.
- *Neocognitron Neural Network.* Successfully demonstrated discrimination of radar signatures of targets using a 9 x 9 channel, 2-layer optical neocognitron neural network using a Damann grating fabricated using electron beam lithography.
- *Vertical Bloch Line (VBL) Memory.* Invented an improved method of reading VBLs in the VBL memory. This improvement uses the bubble movement under an applied magnetic field.

## Programmatic Highlights

CSMT hosted or sponsored the following technical workshops during 1991:

- Second International Workshop on Ballistic Electron Emission Microscopy, held at JPL on January 28, 1991.
- The NASA Astrotech Sensor Workshop, held in Pasadena on January 23–25, 1991.
- The Second International Symposium on Space Terahertz Technology, held at JPL on February 26–28, 1991.
- The Strategic Defense Initiative Organization/Innovative Science and Technology Office Symposium on Nanostructures and Applications, held at the University of Arizona on November 19–20, 1991.

Over the past year, CSMT personnel served on numerous panels and committees:

- Joint Services Electronics Program (JSEP) Technical Review Committee.
- NASA University of Michigan Space Terahertz Technology Center, Technical Representative Committee.
- Concurrent Supercomputing Consortium Policy Board.
- Space Technology Interdependency Group (STIG).
- Defense Intelligence Agency National MASINT Architecture Steering Committee.
- U.S. Air Force Scientific Advisory Board.
- Executive Board of the Electronic Materials and Processing Division, American Vacuum Society.

- Department of Energy Office of Basic Energy Sciences Advisory Board.
- Congressional Office of Technology Assessment Panel on Miniaturization Technologies.

A number of awards were presented to CSMT scientists. Most notable were the following:

- Peter Mark Memorial Award  
William J. Kaiser, for innovative applications of electron tunneling techniques, by the American Vacuum Society.
- Thomas R. Benedict Memorial Award  
Anil P. Thakoor, for the paper, "Electronic Neural Network for Dynamic Resource Allocation," at the American Institute of Aeronautics and Astronautics Computers in Aerospace VIII Conference.
- Lew Allen Award for Excellence  
Michael H. Hecht, for contributing to the elucidation of photovoltaic effects in metal-semiconductor systems and its impact on the understanding of the fundamental mechanisms of Schottky barrier formation.

During 1991, CSMT staff published 193 papers, made 211 presentations and filed 125 new technology reports and patent applications. CSMT also hosted several Distinguished Visiting Scientists, including:

- Ravindra Athale  
Department of Electrical Engineering, George Mason University.
- Michael Spencer  
Department of Physics, Howard University.
- Heinrich Rohrer  
IBM Zürich Research Laboratory, Zürich, Switzerland.
- Francis T. S. Yu  
Department of Electrical Engineering, Pennsylvania State University.
- L. Eric Cross  
Department of Electrical Engineering, Cornell University.

## **Institutional Highlights**

One particular highlight was the installation at Caltech of the Intel Touchstone Delta parallel supercomputer, which currently is the world's fastest computer. The Delta was purchased by the Concurrent Supercomputing Consortium as part of the National High Performance Computing and Communications Program. Consortium members include JPL, Caltech, NASA, the Defense Research Advanced Projects Agency, the National Science Foundation and several Department of Energy Laboratories.



## **I. Solid State Devices**



## Overview

The Solid State Device Research Program is directed toward developing innovative devices for space remote and in-situ sensing, and for data processing. Innovative devices can result from the "standard" structures in innovative materials, such as low and high temperature superconductors, strained-layer superlattices, or diamond films. Innovative devices can also result from "innovative" structures achieved using electron tunneling or nanolithography in standard materials. A final step is to use both innovative structures and innovative materials. A new area of emphasis is the miniaturization of sensors and instruments molded by using the techniques of electronic device fabrication to micromachine silicon into micromechanical and electromechanical sensors and actuators.

## 1991 Major Technical Achievements

### Electron Tunneling

- **Observed** metal band structure effects in carrier transport for the first time using Ballistic Electron Emission Microscopy (BEEM) on  $\text{CoSi}_2/\text{Si}$  diodes fabricated in the Microdevices Laboratory. A new carrier transport mechanism was discovered to govern the performance of  $\text{CoSi}_2/\text{Si}$  photodiodes.
- **Imaged** artificial interface structures with BEEM. The resolution of BEEM was found to consistently meet or exceed theoretical expectations.
- **Characterized** minority carrier transport across a pn junction for the first time with BEEM. The potential profile, collection efficiency, and lateral homogeneity of pn-junctions and other heterostructures can be determined on a microscopic scale with this technique.
- Surface/Interface, Inc., of Mountain View, CA, **announced** a commercial, variable temperature BEEM system.
- **Demonstrated** operation of prototype tunneling infrared sensor. Measured Noise Equivalent Power (NEP)  $8 \times 10^{-10} \text{ W}/\sqrt{\text{Hz}}$ , which is competitive with best available pyroelectric uncooled infrared sensors.
- **Designed** improved tunneling infrared sensor.
- **Developed** new fabrication techniques for improved infrared sensor.
- **Demonstrated** operation of improved tunneling infrared sensor. Sensitivity is 3–5 x better than prototype.
- **Demonstrated** operation of wide-bandwidth transducer element for tunneling accelerometer.

### Superconductivity

- **Performed** first comprehensive study of Y-Ba-Cu-O compositional dependence on laser deposition parameters.

- **Fabricated** the first all-high- $T_C$  superconductor/normal-metal/superconductor (SNS) weak links utilizing nonsuperconducting Y-Ba-Cu-O normal metal layers.
- **Fabricated** high-quality edge-geometry SNS weak links with  $\text{PrBa}_2\text{Cu}_3\text{O}_{7-x}$  normal metal layers.
- **Deposited** in-situ superconducting  $\text{Ba}_6\text{K}_4\text{BiO}_3$  thin films by laser ablation.
- High  $T_C$  microwave filter **accepted** for launch on HTSSE I satellite.

### Submillimeter (Terahertz) Receiver Technology

- **Designed**, fabricated, and tested a 10 element submillimeter wave prototype helium cooled niobium-aluminum oxide niobium superconducting tunnel junction planar array receiver at 230 GHz. An overall receiver noise temperature of 260K DSB was achieved. The planar mixer noise temperature measured 150K DSB and had a conversion loss of 10 dB into a matched load. This is only a factor of four higher than the best waveguide receivers using similar superconducting tunnel junctions at this frequency.
- **Designed**, fabricated, and tested a 200 GHz whiskerless diode subharmonically pumped waveguide mixer to be used as a prototype for the Earth Observing System Microwave Limb Sounder instrument. Obtained mixer noise temperatures below 1600K SSB and a conversion loss less than 9 dB, which surpasses the lowest values ever reported for this type of mixer at this frequency, including those using devices that use whiskered diodes.
- **Designed** new mask sets for 630 GHz Nb- $\text{AlO}_x$ -Nb and NbN-MgO-NbN SIS mixer elements. These new designs employ both single pole and multipole integrated microstrip tuning elements. Preliminary mixer tests show performance better than cooled Schottky mixers. Improvements by a factor of 2 to 3 are expected.
- **Made** first measurements of dispersion in Nb-SiO-Nb microstrip transmission lines over a frequency range of 100 GHz to 800 GHz. These transmission lines show an onset of dispersion near 500 GHz, which is lower than expected. This is critical to the design of submillimeter wave mixer circuits.
- **Improved** a calculational technique to de-embed the 630 GHz mixer circuit using Tucker's quantum theory of mixing. The new technique properly accounts for rf power reflected from the circuit.
- **Waveguide** coupled Nb/ $\text{AlO}_x$ /Nb mixers were put into field receivers at Owens Valley Radio Observatory (OVRO) and the Caltech Submillimeter Observatory (CSO) at 115 and 230 GHz. This establishes Nb/ $\text{AlO}_x$ /Nb tunnel junctions as state-of-the-art, effectively replacing Pb-alloy junctions.
- **Fabricated** waveguide coupled Nb/ $\text{AlO}_x$ /Nb mixers for operation at 500 GHz. Achieved lowest noise temperature at this frequency ( $T_R(\text{DSB}) = 175\text{K}$ ). These devices are now in use at CSO.

- **Fabricated** quasioptically coupled Nb/AlO<sub>x</sub>/Nb mixer elements using twin slot antennas for 500 GHz operation ( $T_R(\text{DSB}) = 420\text{K}$ ).
- **Fabricated** quasioptically coupled Nb/AlO<sub>x</sub>/Nb mixers using log-spiral antennas for broadband coupling.
- **Fabricated** quasioptically coupled Nb/AlO<sub>x</sub>/Nb and NbN/MgO/NbN focal plane arrays (5 x 10) for operation at 230 GHz.
- **Fabricated** Nb/AlO<sub>x</sub>/Nb and NbN/MgO/NbN mixers for waveguide coupled mixers operating at 626 GHz.
- **Developed** a submicron planar SIS junction fabrication process using electron beam lithography.
- **Designed**, fabricated (at Lincoln Laboratory and Chalmers), and tested single barrier varactors (SBV) in a waveguide tripler mount to 200 GHz. **Characterized** the SBV varactor performance over a frequency range from 180 to 210 GHz with various whisker lengths as a function of input pump power to compare performance to our theoretical predictions.
- **Developed** a theory of current saturation in semiconductor varactors that addresses the limitations of these devices at submillimeter wavelengths. With this theory, we predict performance of multipliers at high pump powers and high frequencies much more accurately. This knowledge allows us to optimize device design.
- **Designed** and carried out initial fabrication of a waveguide quintupler mount to 810 GHz.
- **Designed** and carried out initial fabrication of a new planar varactor, the back-to-back barrier-n-n (bbBNN) varactor.
- **Demonstrated** a quantum well oscillator above 700 GHz through a contract to Lincoln Laboratory.
- **Stabilized** a quantum well oscillator at 200 GHz with a 10 kHz full width at maximum half power through the contract to Lincoln Laboratory.
- **Developed** a planarization process based on resist etch back for 1 $\mu\text{m}$  isolated steps in AlGaAs PIN diode structures for millimeter- and submillimeter-wave local oscillators and multipliers.

## Semiconducting Materials: Growth and Characterization

- **Observed** surface plasmon resonances in metallic silicide particles incorporated in MBE-grown silicon. This is the first report of the optical properties of composite materials incorporating metal particles whose size and aspect ratio can be controlled on a nanometer scale. The resonance peaks observed in the absorption spectra of a set of samples have been modeled successfully by Maxwell-Garnett theory. These resonances also appear in the photoresponse of Schottky detectors fabricated from the same structures, indicating that the surface plasmon modes decay into detectable single-particle excitations. These results constitute the first evidence of a new IR detection mechanism based on resonant absorption in nanometer-scale metallic particles.
- **Constructed** a scanning cathodoluminescence imaging system with sensitivity from 400 to 1600 nm for high-resolution imaging in a Scanning Electron Microscope (SEM) in the Microdevices Laboratory. This instrument offers an unprecedented richness of correlated spatial, spectral and polarization-dependent emission data, coupled with conventional SEM images of the same area. The system operates at carrier densities consistent with device operating conditions, and provides images with submicron resolution from which information can be obtained on composition, defects, stress, and carrier transport and recombination. During its first year of operation, it has provided the first definitive evidence of directional strain relief in the vicinity of microcracks in heteroepitaxial GaAs on Si structures.
- **Demonstrated** a technique to obtain photoreflectance measurements of semiconductor structures in the 850–1000 nm range using a Fourier Transform Spectrometer.
- **Installed** and brought into operation a state-of-the-art analytical high-resolution TEM system in the Microdevices Laboratory. This ABT 002B model 200 kV electron microscope has a point-to-point resolution of 1.8 Å and a nanoprobe with a minimum diameter of 5 Å. The TEM is equipped with energy dispersive X-ray (EDX) spectroscopy and is connected to the JPL-Cray for image analysis and simulation. This system was purchased for JPL under the EIC Capital Equipment Program, and is an integrated facility also containing specimen preparation and dedicated photographic equipment. The system provides information on structure, defects, and interface characteristics of a wide range of materials, and played a key role in the discovery of a new subsurface crystal growth technique.
- **Developed** a new MBE-based growth technique in which a metal layer can be grown at a subsurface interface by diffusion through a semiconductor overlayer. A continuous, single-crystal layer of cobalt disilicide under a single-crystal Si capping layer has been achieved using this approach, indicating the potential for fabrication of a variety of metallic structures in semiconductors. This growth mode has been coined "endotaxy" as it occurs *within* the structure rather than on the surface as in conventional "epitaxy". Growth occurs at buried seed nucleation sites, which are prepared by a technique of columnar epitaxy, previously invented in MDL. The newly installed TEM system played a crucial role in elucidating this new phenomenon.

- **Developed** an MOCVD deposition process capable of selective area growth of high-quality GaAs and AlGaAs epitaxial layers on selected areas of a GaAs substrate through openings in a silicon nitride layer masking the substrate. This new fabrication technique utilizes a novel approach for selective growth on nitride-coated substrates, which have been patterned using the electron-beam lithography system housed in the Microdevices Laboratory. The fabrication of patterned AlGaAs structures with dimensions on the 0.1  $\mu\text{m}$  scale has been demonstrated in this system. The growth technique is based on diethylgallium-chloride as a source for gallium, rather than the more commonly used trimethylgallium. Preferential growth of layered structures of GaAs/AlGaAs, with an overall thickness as high as 5  $\mu\text{m}$ , has been demonstrated on the opening with no deposits on the nearby nitride surfaces. These structures have features with lateral dimensions as small as 1000 Å. The grown layers have shown very strong cathodoluminescence signals, indicative of their good optical qualities. This process will make it possible to grow submicron size device structures, such as quantum dot lasers, without a need for post-growth device processing steps such as chemical or plasma etching. This work is a collaborative effort with Professor Kerry Vahala of Caltech.
- **Demonstrated** that simple stain etching of silicon wafers can produce porous layers which luminesce in the red at room temperature. The luminescence is similar to that reported for porous layers produced by more exotic "anodic" etching procedures, which has caused a flurry of excitement because of the implications for silicon-based optoelectronics. In comparison to anodically etched wafers, also produced at JPL, the stain-etched films luminesce somewhat less brightly, but with greater uniformity across the sample. TEM, XPS, and RHEED analyses show the bulk of the stain-etched films to consist of amorphous silicon. This suggests that the most-widely-accepted interpretation of the luminescence as originating from crystalline quantum wires is incorrect. Selective definition of the emitting area has also been demonstrated using a photolithographic mask for ion implantation. Implanted regions etch more rapidly, resulting in patterned emitting features.

### Electronic Device Technology

- **Fabricated** quasi-continuous tone computer generated phase hologram etched in PMMA by E-Beam lithography.
- **Fabricated** room temperature high electron mobility test structures using strained layer quantum wells based on 2 monolayers of InAs interlayered with 3, 4, 5, 6, 7, or 8 monolayers of GaAs. Mobility enhancement is 20% to 80% compared to comparably designed pseudomorphic InGaAs or AlGaAs/GaAs structures. Previous problems were due to device design parameters and defects in low temperature GaAs layers.
- **Developed** MBE In-free sample mount technology giving low wafer defects and low thermal variation over wafer, while permitting RHEED analysis before and during sample growth.

### Microinstrument Technology

- **Demonstrated** a new ultra-high-sensitivity position detection device based on a unique capacitance detection method that shows a sensitivity of at least  $0.001 \text{ nm/Hz}^{1/2}$ . This device has many applications for transducers, including high-performance guidance and control sensors.
- **Fabricated** a high-performance compact microseismometer operating at state-of-the-art sensitivity of  $10 \text{ nano-g/Hz}^{1/2}$  and with a total mass of less than 150 grams.
- **Tested** new microseismometer along with conventional instruments at the world-leading Caltech facility where the new microseismometer detected weak, distant, earthquake activity with sensitivity comparable to the best available seismometers.

### Cultured Neuron Probe

- **Developed** processing steps for fabricating prototype neuron probe with neuron wells by micromachining of silicon.
- **Delivered** prototype probes to J. Pine and G. Buzaki for in-vivo testing.

### Diamond Film Technology

- **Achieved** initial nucleation for diamond growth by ECR plasmas at 13 mTorr and  $600^\circ\text{C}$ . The nucleation of diamond by ECR plasmas can be employed for developing epitaxial diamond growth process.
- **Deposited** boron nitride films containing amorphous, hexagonal and cubic phases by ECR plasmas using  $\text{B}_2\text{H}_6$  and  $\text{N}_2$  as source gases. ECR deposition of BN films is the first step for developing a desired interlayer material to promote nucleation and lattice matching for diamond growth on non-diamond substrates.
- **Demonstrated** diamond depositions on ECR-deposited amorphous BN and cubic SiC films, without pretreating the surface of these films with diamond powder. These results indicate the feasibility of developing a viable substrate technology for diamond film applications.
- **Expanded** diamond film nucleation and deposition parameter space to the pressure range of 10 mTorr to 10 Torr, temperature range of  $400$  to  $750^\circ\text{C}$ , using 2 to 15%  $\text{CH}_4$  and 2 to 10%  $\text{O}_2$  in  $\text{H}_2$  plasmas.
- **Fabricated** boron nitride and diamond film samples for NASA Evaluation of Oxygen Interaction with Materials-Series 3 (EOIM-3) flight experiments.
- **Developed** cathodoluminescence spectroscopy as a characterization technique for diamond films, and **showed** high quality diamond films deposited at 10 Torr and  $600^\circ\text{C}$  with very few nitrogen and non-detectable silicon impurities.

## Electron Tunneling

### Publications

"Micromachined Silicon Tunnel Sensor for Motion Detection"  
T.W. Kenny, S.B. Waltman, J.K. Reynolds and W.J. Kaiser  
Applied Physics Letters, vol. 58, pp. 100–102, January 1991

"Novel Infrared Detector Based on a Tunneling Displacement Transducer"  
T.W. Kenny, W.J. Kaiser, S.B. Waltman and J.K. Reynolds  
Applied Physics Letters, vol. 59, pp. 1820–1822, October 1991

"Electron Tunnel Sensors"  
T.W. Kenny and W.J. Kaiser  
Progress in Precision Engineering, pp. 39–49, May 1991

"New Electron and Hole Spectroscopies Based on Ballistic-Electron-Emission-Microscopy"  
L.D. Bell, W.J. Kaiser, M.H. Hecht and L.C. Davis  
Journal of Vacuum Science and Technology, vol. B 9, 594, 1991

"Ballistic Carrier Spectroscopy of the  $\text{CoSi}_2/\text{Si}$  Interface"  
W.J. Kaiser, M.H. Hecht, R. W. Fathauer, L.D. Bell, E. Y. Lee and L.C. Davis  
Physical Review B, vol. 44, 6546, 1991

"Lateral Tunneling through Voltage Controlled Barriers"  
S.J. Manion, L.D. Bell, W.J. Kaiser, P.D. Maker and R.E. Muller  
Applied Physics Letters, vol. 59, p. 213, 1991

"Time Dependence of Photovoltaic Shifts in Photoelectron Spectroscopy of Semiconductors"  
M.H. Hecht  
Physics Review B, vol. 43, no. 14, p. 12102, 1991

"Electron Tunnel Sensors"  
T.W. Kenny, W.J. Kaiser, J.K. Reynolds, J.A. Podosek, H.K. Rockstad, E.C. Vote and S.B. Waltman  
Journal of Vacuum Science and Technology (accepted)

"Ballistic Electron Emission Microscopy Testing of Quantum Electron Wave Heterostructures"  
G.N. Henderson, T.K. Gaylord, E.N. Glytis, P.N. First and W.J. Kaiser  
Solid State Communications (accepted)

"A New Spectroscopy of Carrier Scattering"  
W.J. Kaiser, L.D. Bell, M.H. Hecht and L.C. Davis  
NATO Science Forum '90 (accepted)

"A New Scanning Probe Microscopy for Imaging Subsurface Interface Structure"  
W.J. Kaiser, L.D. Bell, M.H. Hecht and L.C. Davis  
American Institute of Physics Conference Proceedings (accepted)

### **Invited Presentations**

"Ballistic Electron Emission Microscopy"

W.J. Kaiser

Scanning Probe Microscopy Conference, Santa Barbara, CA, January 11, 1991

"A New Model of Electron Transport in the  $\text{CoSi}_2/\text{Si}(111)$  System"

W.J. Kaiser

BEEM Workshop '91, Pasadena, CA, January 28, 1991

"Photovoltaic Effects in Measurement of Surface Band Bending"

M.H. Hecht

Physics and Chemistry of Semiconductor Interfaces (PCSI), Long Beach, CA, January 29, 1991

"Direct Spectroscopy of Interfaces and Carrier Transport Using BEEM"

L.D. Bell

March Meeting of the American Physical Society, Cincinnati, OH, March 18–22, 1991

"Recent Developments in Ballistic Electron Emission Microscopy"

M.H. Hecht

Seminar at ETH, Zurich, Switzerland, August 20, 1991

"Investigation of Interface Electronic Properties with BEEM"

M.H. Hecht

National Science Foundation Workshop on Epitaxy, Interfaces, Defects, and Processing of Electronic and Photonic Materials, Pittsburgh, PA, November 4–7, 1991

### **Presentations**

"Low Temperature Ballistic Carrier Spectroscopy of  $\text{CoSi}_2/\text{Si}$ "

W.J. Kaiser

Physics and Chemistry of Semiconductor Interfaces (PCSI), Long Beach, CA, January 30, 1991

"Electron Tunnel Sensors"

W.J. Kaiser

Caltech Physics Department Colloquium, Pasadena, CA, February 15, 1991

"Electron Tunnel Sensors"

T.W. Kenny

Instrument Society of America, Bakersfield, CA, March 8, 1991

"Electron Tunnel Sensors"

T.W. Kenny and W.J. Kaiser

6th International Precision Engineering Seminar, Braunschweig, Germany, May 28, 1991

"Observation of Artificial Nanostructures with BEEM"

L.D. Bell

International Conference on Scanning Tunneling Microscopy, Interlaken, Switzerland, August 12–16, 1991

"Observation of Minority Carrier Transport by BEEM"

M.H. Hecht

International Conference on Scanning Tunneling Microscopy, Interlaken, Switzerland,  
August 12-16, 1991

"Surface Photovoltage Effects in Schottky Barriers Associated with Periodic X-Ray  
Sources"

M.H. Hecht

Meeting of the American Vacuum Society, Seattle, WA, November 11-15, 1991

"New BEEM Methods for Semiconductor Interfaces"

L.D. Bell

Meeting of the American Vacuum Society, Seattle, WA, November 11-15, 1991

"Electron Tunnel Sensors"

T.W. Kenny, W.J. Kaiser, J.K. Reynolds, J.A. Podosek, H.K. Rockstad, E.C. Vote and  
S.B. Waltman

1991 American Vacuum Society Symposium, Seattle, WA, November 15, 1991

### **Patent and New Technology Reports**

"A Micromachined Electron Tunneling Infrared Detector"

T.W. Kenny, W.J. Kaiser and S.B. Waltman

New Technology Report NPO-18413, November 7, 1990 (U.S. patent pending)

"Electronically Tunable Elastic Suspension for Sensors"

W.J. Kaiser, T.W. Kenny, S.B. Waltman, J.K. Reynolds and T.R. Van Zandt

New Technology Report NPO-18427, November 14, 1990 (U.S. patent pending)

"Measurement of Surface Potential by Photovoltage Decay"

M.H. Hecht

New Technology Report NPO-18457, December 17, 1990 (filed)

"An Electron Tunneling Magnetometer"

W.J. Kaiser, T.W. Kenny and S.B. Waltman

New Technology Report NPO-18493, February 15, 1991 (U.S. patent pending)

"A Micromachined Silicon Tunnel Sensor for Motion Detection"

T.W. Kenny, S.B. Waltman and W.J. Kaiser

New Technology Report NPO-18513, March 14, 1991 (U.S. patent pending)

"Improved Design for Tunneling Infrared Sensor"

T.W. Kenny and W.J. Kaiser

New Technology Report NPO-18560, April 18, 1991 (filed)

"Growth of Delta-doped Layers on Silicon Charged-coupled Devices for Enhanced  
Ultraviolet Response"

M.E. Hoenk, P.J. Grunthaner, F.J. Grunthaner, R.W. Terhune and M.H. Hecht

New Technology Report NPO-18688, September 23, 1991 (filed)

"Silicon Sample Holder for Molecular Beam Epitaxy"  
M.E. Hoenk, P.J. Grunthaner and F.J. Grunthaner  
New Technology Report NPO-18687, September 23, 1991 (filed)

"Tunnel Effect Measuring Systems and Particle Detectors"  
W.J. Kaiser, S.B. Waltman and T.W. Kenny  
NASA Tech Brief NPO-17362, vol. 13, no. 9, p. 59, September 1989 (U.S. patent pending)

"Formation of Ohmic Gold Contacts on Epitaxial GaAs"  
M.H. Hecht, L.D. Bell and W.J. Kaiser  
NASA Tech. Brief No. NPO-17795, vol. 15, no. 3, p. 58, March 1991

"Charge-carrier Scattering Spectroscopy with BEEM"  
M.H. Hecht, L.D. Bell and W.J. Kaiser  
NASA Tech. Brief No. NPO-18411, November 6, 1990 (accepted)

"Surface Modification Using Low Energy Ground State Ion Beams"  
A. Chutjuan, M.H. Hecht and O.J. Orient  
U.S. Patent No. 4,902,647, March 1, 1991

## Superconductivity

### Publications

"Edge Geometry YBaCuO/Au/Nb SNS Devices"

B.D. Hunt, M.C. Foote and L.J. Bajuk

IEEE Trans. Magnetics, vol. 27, 848, March 1991

"YBaCuO/Au/Nb Sandwich Geometry SNS Weak Links on C-Axis Oriented YBaCuO"

M.C. Foote, B.D. Hunt and L.J. Bajuk

IEEE Trans. Magnetics, vol. 27, 1335, March 1991

"Study of Chemically Etched BiSrCaCuO Surfaces"

R.P. Vasquez and R.M. Housley

Physica C, vol. 175, no. 233, April 15, 1991

"High Tc Superconductor Coplanar Waveguide Filter"

W. Chew, L.J. Bajuk, T.W. Cooley, M.C. Foote, B.D. Hunt, D.L. Rascoe and A.L. Riley

IEEE Elec. Dev. Lett., vol. 12, 197, May 1991

"Chemical Nature of the Barrier in Pb/YBaCuO Tunneling Structures"

R.P. Vasquez, M.C. Foote, B.D. Hunt and L.J. Bajuk

J. Vac. Sci. Technol. A, vol. 9, 570, May/June 1991

"X-ray Photoelectron Spectroscopy Study of Sr and Ba Compounds"

R.P. Vasquez

J. Electron Spectrosc. Relat. Phenom., vol. 56, no. 217, June 1991

"X-ray Photoelectron Spectroscopy Study of Chemically-Etched TlBaCaCuO Thin Film Surfaces"

R.P. Vasquez and W.L. Olson

Physica C, vol. 177, no. 223, June 15, 1991

"All-High-Tc Edge-Geometry Weak Links Utilizing Y-Ba-Cu-O Barrier Layers"

B.D. Hunt, M.C. Foote and L.J. Bajuk

Appl. Phys. Lett., vol. 59, 982, August 19, 1991

"Design and Performance of a High Tc Superconductor Coplanar Waveguide Filter"

W. Chew, A.L. Riley, D.L. Rascoe, B.D. Hunt, M.C. Foote, T.W. Cooley and L.J. Bajuk

IEEE Microwave Theory and Techniques, vol. 39, September 1991

"X-ray Photoelectron Spectroscopy Study of Chemically-Etched Nd-Ce-Cu-O Surfaces"

R.P. Vasquez, A. Gupta and A. Kussmaul

Solid State Commun., vol. 78, no. 303, 1991

"A Low Pass CPW Microwave Filter for the NRL High Temperature Superconductivity Space Experiment"

A.L. Riley, B.D. Hunt, W. Chew, L. Bajuk, M.C. Foote, D.L. Rascoe and T.W. Cooley

Proc. 2nd World Congress on Superconductivity, 1991

"Coplanar Waveguide Microwave Filter of YBaCuO"

W. Chew, A.L. Riley, D.L. Rascoe, B.D. Hunt, M.C. Foote, T.W. Cooley and L.J. Bajuk

Superconductivity Applications for Infrared and Microwave Devices II, Proc. SPIE, 1991

"Interacting and Self-Organized Two-Level States in Tunnel Barriers"

L. Pesenson, R.P. Robertazzi, R.A. Buhrman, S.R. Cypher and B.D. Hunt

Phys. Rev. Lett., vol. 67, p. 2866, 1991

"High Temperature Superconducting Superconductor/Normal Metal/Superconductor Devices"

M.C. Foote, B.D. Hunt and L.J. Bajuk, invited paper

Superconductivity Applications for Infrared and Microwave Devices II, Proc. SPIE, 1991

"All-YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-x</sub> Edge Geometry Weak Links"

B.D. Hunt, L.J. Bajuk, J.B. Barner, M.C. Foote, B.B. Jones and R.P. Vasquez

Progress in High T<sub>c</sub> Superconducting Transistors and Other Devices, Proc. SPIE vol. 1597, 1991

"YBaCuO/Au/Nb Device Structures"

B.D. Hunt, M.C. Foote, L.J. Bajuk and R.P. Vasquez, invited paper

Progress in High Temperature Superconducting Transistors and other Devices, R. Singh, J. Narayan and D.T. Shaw, eds., Proc. SPIE, vol. 1394, 89, 1991

"High-Temperature Superconductor Thin Film Devices for Space Applications"

B.D. Hunt, A. L. Riley, M.C. Foote, W. Chew, L.J. Bajuk, D.L. Rascoe, T.W. Cooley and R.P. Vasquez

Space Microelectronics, vol. 3, 28, Winter 1991 (JPL 410-25-3)

"On the Scaling of Transport Properties in High Temperature Superconductors"

N.-C. Yeh, D.S. Reed, W. Jiang, U. Kriplani, F. Holtzberg, A. Gupta, B.D. Hunt,

R. Vasquez, M. Foote and L. Bajuk

Phys. Rev. B. 1991 (accepted)

"Modeling of Planar Quasi-TEM Superconducting Transmission Lines"

D. Antsos, W. Chew, A.L. Riley, B.D. Hunt, M.C. Foote, L.J. Bajuk, D.L. Rascoe and T.W. Cooley

IEEE Trans. on Microwave Theory and Techniques, 1991 (accepted)

"A Coplanar Waveguide Filter Using Thin Film High Temperature Superconductor"

W. Chew, L.J. Bajuk, T.W. Cooley, M.C. Foote, B.D. Hunt, D.L. Rascoe and A.L. Riley

Proc. 1991 IEEE MTT-S Inter. Microwave Symposium, June 1991 (accepted)

"X-Ray Photoelectron Spectroscopy Study of Inequivalent Oxygen Sites in High Temperature Superconductors"

R.P. Vasquez, B.D. Hunt, M.C. Foote, L.J. Bajuk and W.L. Olson

Physica C, 1991 (accepted)

"X-Ray Photoelectron Spectroscopy Characterization of a Nonsuperconducting Y-Ba-Cu-O SNS Barrier Material"

R.P. Vasquez, B.D. Hunt, M.C. Foote and L.J. Bajuk  
J. Vac. Sci. Technol. A, 1991 (in press)

"Valence Band and Ba Core Level Study of Chemically-Etched YBaCuO"

R.P. Vasquez, M.C. Foote, L. Bajuk and B.D. Hunt  
J. Electron Spectroscopy, 1991 (in press)

### **Invited Presentations**

"High Temperature Superconducting Superconductor/Normal-Metal/Superconductor Devices"

M.C. Foote, B.D. Hunt and L.J. Bajuk

SPIE Symposium on "Superconductivity Applications for Infrared and Microwave Devices II," Orlando, FL, April 1-5, 1991

"All-YBaCuO Edge-Geometry Weak Links"

B.D. Hunt, L.J. Bajuk, M.C. Foote, J.B. Barner, B.B. Jones and R.P. Vasquez

SPIE Symposium on "Progress in High Temperature Superconducting Transistors and Other Devices", San Jose, CA, September 12-13, 1991

"Josephson Devices Operating Above 80 K with Electrical Transport Along the a-Axis Direction"

J.B. Barner, C.T. Rogers, A. Inam, R. Ramesh, B.J. Wilkens, S. Bersey, B.D. Hunt, M.C. Foote, R.P. Vasquez, L.J. Bajuk and B.B. Jones  
ISS'91, Tokyo, Japan, October 14-17, 1991

### **Presentations**

"Thermal Fluctuations, Dimensional Crossover, and Grain Boundary Effects on the dc and ac Vortex Dissipation in High Temperature Superconductors"

N.C. Yeh, D.S. Reed, W. Jiang, U. Kriplani, C.T. Jin, J. Carter, B.D. Hunt, M.C. Foote, R.P. Vasquez, L. Bajuk, F. Holtzberg and A. Gupta

March Meeting of the American Physical Society, March 19, 1991

"Edge Geometry YBaCuO Weak Links"

B.D. Hunt, L.J. Bajuk, M.C. Foote and R.P. Vasquez

March Meeting of the American Physical Society, March 21, 1991

"Coplanar Waveguide Microwave Filter of YBaCuO"

W. Chew, A. L. Riley, D.L. Rascoe, B.D. Hunt, M.C. Foote, T.W. Cooley and L.J. Bajuk  
SPIE Symposium "Superconductivity Applications for Infrared and Microwave Devices II, Orlando, FL, April 1-5, 1991

"X-ray Photoelectron Spectroscopy Study of Chemically-Etched TlBaCaCuO Thin Film Surfaces"

R.P. Vasquez and W.L. Olson

Materials Research Society Spring Meeting, Anaheim, CA, April 29-May 3, 1991

"A Coplanar Waveguide Filter Using Thin Film High Temperature Superconductor"  
W. Chew, L.J. Bajuk, T.W. Cooley, M.C. Foote, B.D. Hunt, D.L. Rascoe and A.L. Riley  
1991 IEEE MTT-S International Microwave Symposium, Boston, MA, June 1991

"All-YBaCuO Edge-Geometry Weak Links"  
B.D. Hunt, L.J. Bajuk, M.C. Foote, J.B. Barner, B.B. Jones and R.P. Vasquez  
Superconductive Electronics Workshop, Fallen Leaf Lake, CA, September 22-26, 1991

"All-High-Tc Edge-Geometry Weak Links Utilizing Y-Ba-Cu-O Barrier Layers"  
B.D. Hunt, M.C. Foote, J.B. Barner, R.P. Vasquez, L.J. Bajuk and B.B. Jones  
DARPA High Temperature Superconductivity Workshop, Seattle, WA, September 30-October 1, 1991

"X-ray Photoelectron Spectroscopy Characterization of a Nonsuperconducting Y-Ba-Cu-O SNS Barrier Material"

R. P. Vasquez, B. D. Hunt, M. C. Foote and L. Bajuk  
38th Annual Symposium of the American Vacuum Society, Seattle, WA, November 11-15, 1991

#### **Patent and New Technology Reports**

"YBaCuO/Au/Nb Sandwich Geometry SNS Weak Links on c-Axis Oriented YBaCuO"  
M.C. Foote, B.D. Hunt and L.J. Bajuk  
New Technology Report NPO-18394, October 29, 1990 (filed)

"High Tc Superconductor Coplanar Waveguide Filter"  
L.J. Bajuk, W. Chew, T.W. Cooley, M.C. Foote, B.D. Hunt, D.L. Rascoe and A.L. Riley  
New Technology Report NPO-18424 November 16, 1990 (filed)

"Epitaxial Heterojunctions of Oxide Semiconductors and Metals on High Temperature Superconductors"  
R.P. Vasquez, B.D. Hunt and M.C. Foote  
New Technology Report NPO-18483, January 22, 1991 (patent pending)

"All-High-Tc Edge Geometry Weak Links Utilizing Y-Ba-Cu-O Barrier Layers"  
B.D. Hunt  
New Technology Report NPO-18552, April 11, 1991 (filed)

## Submillimeter (Terahertz) Receiver Technology

### Publications

"THz Dichroic Plates for Use at High Angles of Incidence"

P.H. Siegel, R.J. Dengler and J.C. Chen

IEEE Microwave and Guided Wave Letters, vol. 1, no. 1, pp. 8–9, January 1991

"The Dielectric-Filled Parabola: A New Millimeter/Submillimeter Wavelength Receiver/Transmitter Front End"

P.H. Siegel and R.J. Dengler

IEEE Trans. Ant. and Prop., vol. 39, no. 1, pp. 40–47, January 1991

"Measured and Computed Performance of a Microstrip Filter Composed of Semi-Insulating GaAs on a Fused Quartz Substrate"

P.H. Siegel, J. Oswald, R.J. Dengler, D.M. Sheen and S.M. Ali

IEEE Microwave and Guided Wave Letters, vol. 1, no. 4, pp. 78–80, April 1991

"Improved Millimeter-Wave Mixer Performance Analysis at Cryogenic Temperatures"

P.H. Siegel, I. Mehdi and J. East

IEEE Microwave and Guided Wave Letters, vol. 1, no. 6, pp. 129–131, June 1991

"Theoretical Performance of Novel Multipliers at Millimeter and Submillimeter Wavelengths"

T.J. Tolmunen, M.A. Frerking

International Journal of Infrared and Millimeter Waves, pp. 1111–1133, October 1991

"Sliding Backshorts For Planar Circuits"

V.M. Lubecke, W.R. McGrath and D.B. Rutledge

Int. J. of Infrared and Millimeter Waves, vol. 12, no. 12, December 1991 (in press)

"Performance of NbN Superconductive Tunnel Junctions as SIS Mixers at 205 GHz"

W.R. McGrath, J.A. Stern, H.H.S. Javadi, S.R. Cypher, B.D. Hunt and H.G. LeDuc

IEEE Transactions on Magnetics, vol. 27, p. 2650, 1991

"Submicron Area NbN/MgO/NbN Tunnel Junctions for SIS Mixer Applications"

H.G. LeDuc, A. Judas, S.R. Cypher, B. Bumble, B.D. Hunt, J.A. Stern

IEEE Transactions on Magnetics, vol. 27, p. 3192, 1991

"Characterization of NbN Films and Tunnel Junctions"

J.A. Stern and H.G. LeDuc

IEEE Transactions on Magnetics, vol. 27, 3196, 1991

"Current Saturation in Submillimeter Wave Varactors"

E. Kollberg, T. Tolmunen, M. Frerking, J. East

IEEE Microwave Theory and Techniques (accepted)

"Modeling of Planar Varactor Frequency Multiplier Devices with Blocking Barriers"

U. Lieneweg, T.J. Tolmunen, M.A. Frerking and J. Maserjian

IEEE Microwave Theory and Techniques (accepted)

"Measurements on a 215 GHz Subharmonically Pumped Waveguide Mixer Using Planar Back to Back Air Bridge Schottky Diodes"  
P.H. Siegel, R.J. Dengler, I. Mehdi, J.E. Oswald, W.L. Bishop, T.W. Crowe and R.J. Mattauch  
IEEE Trans. Microwave Theory and Techniques, December 1991 (filed)

### **Invited Presentations**

"EOS-Microwave Limb Sounder: A View from the Front"  
P.H. Siegel  
Second International Conference on Space Terahertz Technology, March 1991

### **Presentations**

"Theoretical Efficiency of Multiplier Devices"  
T. Tolmunen and M. Frerking  
Proceedings of the Second International Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Design of Planar Varactor Frequency Multiplier Devices with Blocking Barriers"  
U. Lieneweg, T. Tolmunen, M. Frerking and J. Maserjian  
Proceedings of the Second International Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Current Saturation in Submillimeter Wave Varactors"  
E. Kollberg, T. Tolmunen, M. Frerking and J. East  
Proceedings of the Second International Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Modeling of Planar Varactor Frequency Multiplier Devices with Blocking Barriers"  
U. Lieneweg, T.J. Tolmunen, M.A. Frerking and J. Maserjian  
Proceedings of the Second International Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Sliding Backshorts For Planar Circuits"  
V.M. Lubecke, W.R. McGrath and D.B. Rutledge  
Second Int'l. Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Low Noise 205 GHz SIS Mixers Using High Current Density Nb and NbN Tunnel Junctions"  
W.R. McGrath, H.H.S. Javadi, S.R. Cypher, B. Bumble, B.D. Hunt and H.G. LeDuc  
Second Int'l. Symposium on Space Terahertz Technology, Pasadena, CA, February 26-28, 1991

"Improved Millimeter Wave Mixer Performance Analysis Using a Drift Diffusion Capacitance Model"  
I. Mehdi and P.H. Siegel  
1991 IEEE International Microwave Symposium Digest, pp. 887-890, June 1991

"An Adjustable RF Tuning Element for Microwave, Millimeter Wave and Submillimeter Wave"

V.M. Lubecke, W.R. McGrath and D.B. Rutledge

Technology 2001 Conference, San Jose, CA, December 3–5, 1991

"A Novel Noncontacting Waveguide Backshort for Millimeter and Submillimeter Wave Frequencies"

W.R. McGrath

Technology 2001 Conference, San Jose, CA, December 3–5, 1991

"A Planar Quasi-Optical SIS Receiver Suitable for Array Applications"

P.A. Stimson, R.J. Dengler, P.H. Siegel and H.G. LeDuc

Third International Conference on Space Terahertz Technology, December 1991  
(submitted)

"A Planar Quasi-Optical SIS Receiver Suitable for Array Applications"

P.A. Stimson, R.J. Dengler, P.H. Siegel and H.G. LeDuc

1991 IEEE International Microwave Symposium, December 1991 (submitted)

"Design and Measurements of a 210 GHz Subharmonically Pumped GaAs MMIC Mixer"

P.H. Siegel, S. Weinreb, S. Duncan, W. Berk, A. Eskandarian and D.W. Tu

1991 IEEE International Microwave Symposium, December 1991 (submitted)

"A 200 GHz Planar Diode Subharmonically Pumped Waveguide Mixer with State-of-the-Art Performance"

P.H. Siegel, R.J. Dengler, I. Mehdi, W. Bishop and T. Crowe

1991 IEEE International Microwave Symposium, December 1991 (submitted)

### **Patent and New Technology Reports**

"Optically Switched Submillimeter-Wave Oscillator"

J. Maserjian and M.G. Spencer (Distinguished Visiting Scientist from Howard University)

New Technology Report, NPO-18547, April 3, 1991 (filed)

"Design of Planar Varactor Frequency Multiplier Devices with Blocking Barriers"

U. Lieneweg, T.J. Tolmunen, M.A. Frerking and J. Maserjian

New Technology Report, NPO-18428, November 21, 1990 (filed)

"Adjustable RF Tuning Elements for Microwave, Millimeter Wave and Submillimeter Wave Integrated Circuits"

W.R. McGrath and V.M. Lubecke

NASA Tech. Brief NPO-18359, September 7, 1990 (patent pending)

"Making High Pass Filters for Submillimeter Waves"

P.H. Siegel and R.J. Dengler

NASA Tech. Brief NPO-17992, vol. 15, no. 8, pp. 83–84, August 1991

"Rugged Noncontact Backshorts for Waveguide"

W.R. McGrath

NASA Tech. Brief NPO-18091, vol. 16, no. 5, p. 26, May 1992 (patent pending)

## **Semiconducting Materials: Growth and Characterization**

### **Publications**

"Selective Growth in the  $\text{CoSi}_2/\text{Si}$  System by Molecular Beam Epitaxy"

T. George and R.W. Fathauer

Proceedings of MRS Conference, Spring 1991

"Electron Microdiffraction Investigation of Strain-Symmetrised  $\text{Si}/\text{Si}_{0.5}\text{Ge}_{0.5}$  Structures"

W.T. Pike, R.A.A. Kubiak, E.H.C. Parker and T.E. Whall

Proceedings of MRS Conference, Spring 1991

"Optical Properties and Internal Photoemission in Epitaxial Composites of  $\text{CoSi}_2$  Particles in Silicon"

J.R. Jimenez, L.J. Schowalter and R.W. Fathauer

Proceedings of MRS Conference, Spring 1991

"Absorption and Photoluminescence of Ultrathin Pseudomorphic  $\text{InAs}/\text{GaAs}$  Quantum Wells"

A. Ksenzov, F.G. Grunthaler, J.K. Liu, D.H. Rich, R.W. Terhune and B.A. Wilson

Physical Review B, vol. 43, 14574, 1991

"Controllable Surface-Plasmon Resonance in Engineered Nanometer Epitaxial Silicide Particles Embedded in Silicon"

R.W. Fathauer, A. Ksenzov, J.M. Iannelli and T. George

Physical Review B, vol. 44, pp. 1345–1348, July 15, 1991

"Optical Absorption by Free Holes in Heavily Doped  $\text{GaAs}$ "

M.L. Huberman, A. Ksenzov, A. Larsson, R.W. Terhune and J. Maserjian

Physical Review B, vol. 44, 1128, 1991

"Polarized Cathodoluminescence Study of Uniaxial and Biaxial Stress in  $\text{GaAs}/\text{Si}$ "

D. Rich, A. Ksenzov, R.W. Terhune and B.A. Wilson

Physical Review B, vol. 43, 6836, 1991

"Subsurface Growth of  $\text{CoSi}_2$  by Deposition of Co on Si-Capped  $\text{CoSi}$  Seed Regions"

R.W. Fathauer, T. George and W.T. Pike

MRS Conference Proceedings, 1991 (accepted)

### **Invited Presentations**

"Silicon Molecular Beam Epitaxy"

R. Fathauer, Chair

1991 Spring Materials Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"Fabrication and Properties of Columnar Metal Silicide Structures Embedded in Silicon"

R. Fathauer

Gordon Conference on Crystal Growth, Plymouth, NH, July 15–19, 1991

"Diffusion-Controlled Growth of Subsurface CoSi Embedded in Si Using an MBE Technique"

T. George

Gordon Conference on Crystal Growth, Plymouth, NH, July 15–19, 1991

## **Presentations**

"Polarized Cathodoluminescence Study of Uniaxial and Biaxial Stress in GaAs/Si"

D.H. Rich, A. Ksendzov, R.W. Terhune, F.J. Grunthaner and B.A. Wilson

APS Meeting, Cincinnati, OH, March 18–22, 1991

"Absorption and Photoluminescence of InAs/GaAs Quantum Wells"

A. Ksendzov, F.J. Grunthaner, D.H. Rich, R.W. Terhune and B.A. Wilson

APS Meeting, Cincinnati, OH, March 18–22, 1991

"Optical and Structural Characterization of InAs/GaAs Quantum Wells"

A. Ksendzov, T. George, F.J. Grunthaner, J.K. Liu, D.H. Rich, R.W. Terhune, B.A. Wilson

1991 Spring Materials Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"Critical Thickness Anisotropy in Highly Carbon Doped p-type (100) GaAs Layers Grown by Metalorganic Molecular Beam Epitaxy"

T. George (with UC Berkeley)

1991 Spring Materials Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"Electron Microdiffraction Investigation of Strain-symmetrised Si/Si<sub>0.5</sub>Ge<sub>0.5</sub> Structures"

W.T. Pike (with Cambridge University, U.K.)

1991 Spring Materials Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"Fabrication and Properties of Epitaxial Silicide/Silicon Structures with Nanometer Control in Three Dimensions"

R. Fathauer

1991 Spring Materials Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"Selective Growth in the CoSi<sub>2</sub>/Si System by Molecular Beam Epitaxy"

T. George

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"Characterization of P/N Semiconductor Structures"

J. Singletary

Technet 91 Conference, Denver, CO, October 1991

"Fabrication of Light-Emitting Silicon with Stain Etches and Evidence that Luminescence Originates in Amorphous Layers"

R.W. Fathauer, T. George, A. Ksendzov, T.L. Lin, W.T. Pike and R.P. Vasquez

Late News Session, Fall Materials Research Society Meeting, Boston, MA, November 1, 1991

## **Patent and New Technology Reports**

**"Growing Cobalt Silicide Columns in Silicon"**

R.W. Fathauer

NASA Tech. Brief No. NPO-17835, vol. 15, no. 3, p. 121, June 1991

**"Subsurface Crystalline Growth of Thin Films and Structures in Crystalline Substrates"**

R. W. Fathauer, T. George and W.T. Pike

New Technology Report NPO-18624, October 1991 (filed)

**"Molecular Beam Epitaxy of  $\text{IrSi}_3$ "**

T.L. Lin

NASA Tech. Brief No. NPO-17953, vol. 15, no. 2, p. 60, February 1991

**"Method and Apparatus for Measuring P/N Semiconductor Structures"**

J. Singletery

Patent Application submitted by Cornell University

**"Pinhole-free Growth of Epitaxial  $\text{CoSi}_2$  Film on  $\text{Si}(111)$ "**

T.L. Lin, R. Fathauer and S. Nieh

U.S. Patent No. 5,010,037, April 23, 1991

**"Preparation of Dilute Magnetic Semiconductor Films by MOCVD"**

A. Nouhi and R.J. Stirn

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## Electronic Device Technology

### Publications

"Observation of a Correlation Between Twin Orientation and Substrate Step Direction in Thin GaAs Films Grown on Intentionally Misoriented Si (100)"

K.C. Rajkumar, A. Madhukar, J.K. Liu and F. J. Grunthaner  
Appl. Phys. L, vol. 56, 1160 (1990)

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P. Lao, W.C. Tang, K.C. Rajkumar, K.C. Guha, A. Madhukar, J.K. Liu and F. J. Grunthaner  
J. Appl. Phys., vol. 67, 6445 (1990)

"Correlations between the Interfacial Chemistry and Current-Voltage Behavior of n-GaAs/Liquid Junctions"

B.J. Tufts, L.G. Casagrande, N.S. Lewis and F.J. Grunthaner  
Appl. Phys. L., vol. 57, 1242 (1990)

"Analytic Solution for the Current-Voltage Characteristic of Two Mesoscopic Tunnel Junctions Coupled in Series"

M. Amman, R. Wilkins, E. Ben-Jacob, P.D. Maker and R.C. Jaklevic  
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"CCD Image Sensor with Differential, Pyramidal Output for Lossless Image Compression"

S.E. Kemeny, H. Torbey, H. Meadows, E.R. Fossum, R. Bredthauer and M. LaShell  
Proc. 1991 IEEE Custom Integrated Circuits Conf., San Diego, CA, May 1991

"III-V Charge-coupled Devices"

E.R. Fossum  
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"Report of the Sensor Readout Electronics Panel"

E.R. Fossum  
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"On-chip Focal-plane Image Processing"

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M. Kim, J.J. Rosenberg, R.P. Smith, R.M. Weikle, II, J.B. Hacker, M.P. DeLisio and D.B. Rutledge  
Microwave and Guided Wave Letters, vol. 1, no. 322, November, 1991

"Ku-Band High Efficiency, High Gain Pseudomorphic HEMT"

P.M. Smith, W.F. Kopp, P. Ho, P.C. Chao, R.P. Smith, K. Nordheden and J.M. Ballingall  
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"Wire Transfer of Charge Packets Using a CCD-BBD Structure for Charge-Domain Signal Processing"

E.R. Fossum, S. E. Kemeny, R.A. Bredthauer and M.A. LaShell  
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"Digitally Programmable Gain Control Circuit for Charge-domain Signal Processing"

E.R. Fossum, S.E. Kemeny, R.A. Bredthauer and M.A. LaShell  
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"A Resistive-Gate AlGaAs/GaAs 2DEG CCD with High Transfer Efficiency at 1 GHz"

J.-I. Song, D.V. Rossi, S.-H. Xin, W.I. Wang and E.R. Fossum  
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E.R. Fossum, J.-I. Song and D.V. Rossi  
IEEE Trans. Electron Devices, vol. ED-38(5), pp. 1182-1192 (1991)

"A Resistive-Gate In<sub>0.53</sub>Ga<sub>0.47</sub>As/InP Heterostructure CCD"

D.V. Rossi, J.-I. Song, E.R. Fossum, P.D. Kirchner, G.D. Pettit and J.M. Woodall  
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CCDs and Optical Sensors II, Proc. SPIE, vol. 1447, p. 24 (1991)

"Two Dimensional Electron Gas Charge-coupled Devices" (extended abstract)

E.R. Fossum, J.-I. Song and D.V. Rossi  
Proc. SPIE, vol. 1447, p. 23 (1991)

"Future Directions in Focal-Plane Signal Processing for Space-borne Scientific Imagers"

E.R. Fossum  
Proc. SPIE, vol. 1541, pp. 62-67 (1991)

"Analog Dynamic Random Access Memory (ADRAM) Unit Cell Implemented in Charge Domain"

B. Pain and E.R. Fossum  
IEEE Trans. on Electron Devices, vol. 38(1), pp. 178-179 (1991)

"Polarized-Cathodoluminescence Study of Uniaxial and Biaxial Stress in GaAs/Si"

D.H. Rich, A. Ksendov, R.W. Terhune, F.J. Grunthaner and B.A. Wilson  
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"Absorption and Photoluminescence of Ultrathin Pseudomorphic InAs/GaAs Quantum-Wells"

A. Ksendov, F. J. Grunthaner, J.K. Liu, D.H. Rich and R.W. Terhune  
Phys. Rev. B 43, 4574 (1991)

### **Invited Presentations**

"Synthesis of Novel Electronic Materials Through Dynamic Surface and Interface Chemistry ( Molecular Beam Epitaxy )"

F.J. Grunthaner

Physics and Materials Science Colloquium, University of Southern California, Los Angeles, CA, February 15, 1991

"III-V CCDs"

E.R. Fossum

University of California at Davis, May 1991

"III-V CCDs"

E.R. Fossum

TRIUMF, University of British Columbia, Vancouver, Canada, June 1991

"III-V Charge-Coupled Devices"

E.R. Fossum

Proc. of 1991 IEEE Device Research Symposium Workshop on Charge-Coupled Devices  
Waterloo, Ontario, June 1991

"Atomic-Scale Chemical Characterization, Control and Synthesis of Semiconductor Surfaces and Interfaces"

F.J. Grunthaner

International Conference on Solid State Devices and Materials (SSDM-91), Yokohama, Japan, August 28, 1991

"Solid-State Image Sensors" (5 lectures)

E.R. Fossum

Norwegian Defence Research Establishment, Oslo, Norway, September 1991

"On-chip Focal-plane Image Processing"

E.R. Fossum

1991 Symposium on Advanced Image-Acquisition Technology (SAIT91) Tokyo, Japan, November 1991

"III-V CCDs"

E.R. Fossum

IEEE Device Research Symposium, Charlottesville, VA, December 1991

### **Presentations**

"Synthesis and Characterization of Highly-strained Pseudomorphic GaAs/InAs/GaAs Quantum Wells and InAs/GaAs Interfaces"

F.J. Grunthaner, K. Delgadillo, A. Ksendov, D. Rich, T. George and J.K. Liu  
PCSI-18, Long Beach, CA, January 1991

"Update on Focal-plane Image Processing Research"

S.E. Kemeny, E-S. Eid, S. Mendis and E.R. Fossum

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"Two Dimensional Electron Gas Charge-coupled Devices"

E.R. Fossum, J.-I. Song and D.V. Rossi

San Jose, CA, February 1991 (extended abstract)

"Polarized-Cathodoluminescence Study of Uniaxial and Biaxial Stress in GaAs/Si"

D.H. Rich, A. Ksendov, R.W. Terhune, F.J. Grunthaner and B.A. Wilson

APS March Meeting, Cincinnati, OH, March 1991

"Absorption and Photoluminescence of Ultrathin Pseudomorphic InAs/GaAs Quantum-Wells"

A. Ksendov, F.J. Grunthaner, J.K. Liu, D.H. Rich and R.W. Terhune

APS March Meeting, Cincinnati, OH, March 1991

"CCD Image Sensor with Differential, Pyramidal Output for Lossless Image Compression"

S.E. Kemeny, H. Torbey, H. Meadows, E.R. Fossum, R. Bredthauer and M. LaShell

1991 IEEE Custom Integrated Circuits Conference, San Diego, CA, May 1991

"Future Directions in Focal-Plane Signal Processing for Space-borne Scientific Imagers"

E.R. Fossum

SPIE Conference on Focal-Plane Signal Processing, San Diego, CA, July 1991

"Hough Transform Computer Generated Holograms: New Output Format"

N. Carender, D. Casasent, F. Coetzee, D. Yu and P. Maker

SPIE, July 1991

"Ku-band Power Amplifier Using Pseudomorphic HEMT Devices for Improved Efficiency"

D. Helms, J.J. Komiak, W.F. Kopp, P. Ho, P.M. Smith, R.P. Smith and D. Hogue

1991 MTT-S International Microwave Symposium

### **Patent and New Technology Reports**

"Time Delay and Integration Architecture for Correction of Off-axis Error"

E.R. Fossum and R.W. Capps

New Technology Report NPO-18466 (1991)

"Analog Optical Link for Focal-Plane Readout"

E.R. Fossum, A.G. Larsson and J. Maserjian

New Technology Report NPO-18481 (1991)

"Monolithic Image Sensor with Photon-Counting Pixels"

E.R. Fossum

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"Doping to Reduce Base Resistance of Bipolar Transistors"

T.L. Lin

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## **Cultured Neuron Probe**

### **Presentations**

"Cultured Neuron Probes"

J. Pine, H.K. Rockstad and G. Buzaki

National Institutes of Health Workshop, Bethesda, MD, October 1991

## **Diamond Film Technology**

### **Publications**

"Diamond Film Deposition Using Microwave Plasmas Under Low Pressures"

Y.H. Shing, F.S. Pool and D.H. Rich

Applications of Diamond Films and Related Materials, Editors: Y. Tzeng, M. Yoshikawa, M. Murakawa, A. Feldman, Materials Science Monographs, 73, p.497, Elsevier Science Publishers, 1991

"Low-Pressure Microwave Plasma Deposition and Nucleation of Diamond Films

Y.H. Shing, F.S. Pool and D.H. Rich

Journal of Thin Solid Films (accepted)

"Dependence of the Cathodoluminescence of Diamond Films on Deposition Temperature"

Y.H. Shing, F.S. Pool and D.H. Rich

Journal of Applied Physics (accepted)

### **Presentations**

"Low-Pressure Microwave Plasma Deposition of Diamond and Related Films"

Y.H. Shing

Army Materials Technology Laboratory, Watertown, MA, May 14, 1991

"Diamond and Diamond-Like Films Deposited by Low-Pressure Microwave Plasmas for EOIM-3 Experiments"

Y.H. Shing

SDIO Workshop for Sample Providers to EOIM-3 Flight Experiments, Pasadena, CA, May 30, 1991

"Diamond Film Deposition Using Microwave Plasmas Under Low Pressures"

Y.H. Shing, F.S. Pool and D.H. Rich

Applied Diamond Conference, Auburn, AL, August 22, 1991

"Diamond Film Technology"

Y.H. Shing

SDIO/IST Annual Program Review, November 22, 1991

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"Interlayer Applications for Diamond Film Nucleation, Adhesion and Heteroepitaxial Growth"

Y.H. Shing

New Technology Report, NPO-18502, February 18, 1991 (filed)

"Diamond and Diamond-Like Composite Films for Tribological and Protective Coatings"

Y.H. Shing

New Technology Report, NPO-18501, February 1991 (filed)

"Deposition of Diamond-Like Films by ECR Microwave Plasma"

F.S. Pool and Y.H. Shing

NASA Tech. Brief NPO-18094, vol. 15, no. 10, p. 42, October 1991

"Deposition of Diamond-Like Films by ECR Microwave Plasma"

Y.H. Shing and F.S. Pool

Patent Application, March 29, 1991 (filed)



## II. Photonics



## Overview

This section concentrates on optoelectronic materials and devices. Optical processing is included in the section on Advanced Computing. Optoelectronic devices that generate, detect, modulate, or switch electromagnetic radiation are being developed for a variety of space applications. The program includes spatial light modulators, solid state lasers, optoelectronic integrated circuits, nonlinear optical materials and devices, fiber optics, and optical networking photovoltaic technology and optical processing.

## 1991 Major Technical Achievements

### Spatial Light Modulators

- **Achieved** record high contrast ratios ( $> 60:1$ ) in low-power ( $< 100 \text{ mW/cm}^2$ ) optically-addressed spatial light modulator (O-SLM) consisting of periodically  $\delta$ -doped InGaAs/GaAs multiple quantum well structures. This is the first demonstration of a high contrast ratio semiconductor-based O-SLM appropriate for monolithic integration with other semiconductor devices.
- **Demonstrated** pixelation of these O-SLM structures into arrays for applications such as image processing. Imaging cathodoluminescence measurements reveal that pixelation ( $50 \mu\text{m} \times 50 \mu\text{m}$ ) does not significantly degrade the effective carrier lifetime, and thus should not affect the performance. This is an important step in assessing the feasibility of fabricating high-performance O-SLM arrays. While further improvements in performance are still anticipated, these device parameters are now within the range required for a variety of practical applications.

### Lasers

- **Designed and fabricated** single-mode lasers operating at 730–745 nm. These lasers are in a ridge-waveguide configuration and consist of a single-quantum-well GRIN structure with AlGaAs active regions, as required to push the emission to shorter wavelengths than for commercially available GaAs lasers. Facet coating, heat sinking and bonding processes have been developed for these lasers to permit fabrication and delivery of operational lasers for system integration and testing. CW output powers in excess of 20 mW have been demonstrated.
- **Delivered** 735 nm diode lasers to LaRC and GSFC for prototype testing in lidar instruments being developed for atmospheric wind sounding. These lasers, which are not available commercially, were developed under NASA Code R funding. The threshold currents and output power of the delivered lasers were well beyond the required specification. Further work will be required to achieve the desired long-term stability and reliability.
- **Demonstrated** monolithic dual-wavelength grating surface-emitting arrays at 9050 and 9250 Å. Such sources will be used in wavelength-division multiplexed local-area networks.

- **Demonstrated** first diode lasers with mixed first and second order, and nonresonant gratings. A comparison of the 1/2 mixed grating lasers with 2/2 conventional lasers on the same chip revealed improvements in the threshold current, external quantum efficiency and a complete elimination of diffraction ripples in vertical far field (this is because there is only one emitting region, rather than two).
- **Demonstrated** semiconductor laser operating at 1.111  $\mu\text{m}$  with a threshold current of  $\sim 600 \text{ A/cm}^2$ . These lasers and those at nearby wavelengths are being used for spectroscopic measurements and optical addressing schemes.
- **Demonstrated** for the first time a new semiconductor laser structure capable of providing near infrared emission. The new approach involves the growth of pseudomorphically strained In(Ga)As multi-quantum-well active layers, InGaAs(P) barrier and index-guiding layers on InP substrates. The first broad-area lasers in this materials system have been fabricated in the Microdevices Laboratory, and exhibit pulsed operation at  $\sim 1.8 \mu\text{m}$ , with threshold currents  $\sim 3 \text{ kA/cm}^2$ . Modification of the structure can theoretically yield lasers covering the wavelength range of 1.6–2.3  $\mu\text{m}$ . Semiconductor lasers emitting in this range are desired for spectroscopic applications, and can be used directly, or as injection-locking sources for solid-state lasers. For example, emission at 2.1  $\mu\text{m}$  is desired for injection locking in the LAWS instrument.
- **Fabricated** high-power ridge-waveguide 940 nm lasers with threshold currents of less than 10 mA, and external quantum efficiencies of more than 60%. The lasers consist of MBE-grown single-quantum-well GRIN structures with pseudomorphically strained InGaAs active regions, and emit more than 80 mW of power at current levels of  $\sim 100 \text{ mA}$ . The lasers operate in single spatial mode with many longitudinal modes. The multi-longitudinal mode operation is mainly due to the properties of the strained-quantum-well InGaAs active region used in the structure to achieve the desired wavelength of 940 nm. Several devices have been delivered to Section 322 for evaluation as sources for water vapor spectroscopy. The successful fabrication of second and third order gratings on these laser structures using MDL's electron-beam lithography facility has also been demonstrated. The latter is a required step towards the achievement of high-spectral-purity, tunable lasers at this wavelength desired for NASA applications.
- **Developed** growth process for  $>1 \mu\text{m}$  strained-layer lasers, and demonstrated lasing at 1.088  $\mu\text{m}$  with a threshold of  $\sim 2 \text{ kA/cm}^2$ . These lasers are being developed for a new He magnetometer instrument. Further refinement of the growth parameters are underway to lower the threshold.
- **Prepared** a wafer of low-threshold ( $<50 \text{ mA}$ ) ridge waveguide AlGaAs/InGaAs/GaAs lasers, which, in collaboration with Cornell University, were fabricated into laterally-coupled distributed feedback lasers. This is a new approach to achieve efficient tunable lasers, which avoids the difficult step of regrowth over a grating structure.
- **Demonstrated** integrable laser structures incorporating  $45^\circ$  mirrors implemented in GaAs and InGaAs quantum-well lasers. These lasers were developed as part of an integrated optoelectronic neural network.

## Optoelectronic Materials and Characterization

- **Developed** a multilayer resist/metal/resist process for the lithography of an integrated spectrometer structure. Etching a sample SiO<sub>2</sub> wafer containing the grating pattern reproduced the 0.25  $\mu\text{m}$  pattern with no discernible ripple.
- **Demonstrated** planar LPE regrowth of AlGaAs over wet-etched, e-beam-defined gratings in n<sup>+</sup> GaAs. This is a key step towards realizing tunable GaAs-based monolithically integrated lasers.
- **Demonstrated** strong photo-optic effects in a periodically delta-doped InGaAs/GaAs multi-quantum well (MQW) structure through optically induced Stark shifts of the QW excitonic resonances. The effect has been implemented in a novel high-contrast-ratio, optically addressed QW spatial light modulator.
- **Demonstrated** through TEM analysis that higher quality SiGe/Si heteroepitaxial layers are obtained at growth temperatures below those originally thought to be optimal. Materials grown below 400 °C exhibit significantly lower densities of defects than those grown in the 450–550 °C temperature range more typically employed. Also demonstrated the advantages of using elemental B evaporated from a high temperature Knudsen cell as a dopant source. The utilization of these results has led to significant improvements in the performance of SiGe HIP detectors through a reduction of the thermally induced dark current. The elimination of dislocation-induced conduction paths has resulted in dark currents close to theoretical limits.

## Optoelectronic Integrated Circuits

- **Demonstrated** new OEICs consisting of DHPT, biasing MESFET, driving MESFET, and LED: The quantum efficiencies of the LED and the phototransistor were 0.01 W/A and 1.0 A/W, respectively. The transconductance ( $g_m$ ) of the MESFETs was ~20 mS/mm for a 9- $\mu\text{m}$ -gate length and a 100- $\mu\text{m}$ -gate width. This can be further improved by reducing the gate length of the MESFET. The current level through the LED is ~1.2 mA at a supply voltage of 2.0 V; thus the electrical power consumption of each circuit is ~2.4 mW. With a thin AlAs etch stop layer, the pinch-off voltage of the MESFETs could be controlled over a large area, and the leakage currents held below 100 nA @ 2 V.
- **Achieved** successful implementation of 4 x 4 array of optical neurons based on this OEIC technology. Each optical neuron exhibits a response time of 5  $\mu\text{s}$ , a switching input light power of 2  $\mu\text{W}$ , and thus an optical switching energy of 10 pJ per neuron.
- **Achieved** high-performance optical neurons utilizing an optical FET (OPFET) as a light detector. The responsivity of the first-generation OPFET was measured to be 0.3 A/W. Completed optical neurons exhibited a differential switching input light power of 54 nW and a differential LED output power of 4.3  $\mu\text{W}$ , which yielded an optical gain of 80. The electrical power dissipation was 1.8 mW, the response time of each neuron was 700  $\mu\text{s}$ , and the differential optical switching energy was 38 pJ per neuron, sufficiently low for a realistic implementation in a 32 x 32 array.

- **Achieved** a high-responsivity OPFET (160 A/W) in an integrable format. The dimensions of the new OPFET (without gate) were 18  $\mu\text{m}$  (source-to-drain spacing) and 30  $\mu\text{m}$  (width).

## Infrared Detectors

- **Achieved** extension of the LWIR photoresponse to 25  $\mu\text{m}$  in Si-based HIP detectors. Quantum efficiencies and detectivities at 15  $\mu\text{m}$  of 2% and  $3 \times 10^9 \text{ cm Hz}^{1/2}\text{W}^{-1}$ , respectively, at 25 K have been observed.
- **Demonstrated** the advantages of using elemental B evaporated from a high temperature Knudsen cell as a dopant source in the fabrication of SiGe/Si HIP detectors. TEM analyses further indicated that growth at reduced substrate temperatures results in fewer defects. The device dark current has been reduced significantly through these procedures. Further increases in the operating temperature for background-limited performance are expected for optimized detectors.
- **Incorporated** an optical cavity structure into 128x128 HIP detector arrays consisting of a thick amorphous silicon insulating layer, and an aluminum reflector layer. The optical cavity improved the quantum efficiency of the detectors by a factor of  $\sim 4$ . The best performance obtained to date are quantum efficiencies of 4% at 8  $\mu\text{m}$  and 1% at 12  $\mu\text{m}$  at 40 K. Further improvement is anticipated through optimization of the pixel structure and the incorporation of antireflection coatings.
- **Delivered** an HIP detector array to Rockwell as part of a collaboration to integrate JPL-fabricated arrays in a hybrid configuration with bump-bonded readout electronics. Mask design specifications were provided by Rockwell for designing a detector array matched to their readout format. A 128 x 128 array was fabricated at JPL and bump bonded to readout circuitry by Rockwell. Test devices on the same wafer were characterized, showing 18  $\mu\text{m}$  cutoff and QE's of 2% in the 8–12  $\mu\text{m}$  range. Measurements of the leakage current indicate that the performance of these arrays will be background limited (BLIP) for 300 K backgrounds (as in EOS applications) for temperatures  $< 40 \text{ K}$ . However, the predicted performance could not be fully tested in this first attempt, as the MUX electronics suffered from carrier freeze out at somewhat higher temperatures. The second attempt will involve a detector array with a shorter wavelength cutoff designed for higher temperature operation.
- Lincoln Laboratory has **picked up** the JPL-pioneered HIP detector technology, and has **succeeded in fabricating** an array monolithically integrated with CCD readout electronics. Although they have not yet been able to reproduce the detector performance obtained at JPL, this is a very promising step forward in implementing this new LWIR technology for space applications.
- **Achieved** a factor of 50 improvement in the performance of GaAs/AlGaAs HIP detectors through new growth techniques aimed at reducing the dopant diffusion which had previously precluded LWIR operation. Optical cavities were also incorporated into the device structure.

- **Approached** by numerous industries and laboratories concerning possible technology transfer and/or collaborations in the development of large-format HIP arrays. In addition to the ongoing collaboration with Rockwell, JPL has been contacted by Hughes, LORAL, Kodak, and David Sarnoff Laboratories. Some of this interest was stimulated by a presentation at the Meeting of the IRIS Specialty Group on Infrared Detectors, which was thought by many to be the best paper at the meeting.
- **Fabricated** Si homojunction detectors using MBE growth of Sb-doped barrier layers and B-doped emitter layers. Zero-bias cutoff wavelengths of  $>12\text{ }\mu\text{m}$ ,  $\sim 12\text{ }\mu\text{m}$  and  $5.5\text{ }\mu\text{m}$  were measured for detectors with barrier thicknesses of  $1\text{ k}\text{\AA}$ ,  $1.5\text{ k}\text{\AA}$ , and  $2\text{ k}\text{\AA}$ , respectively. The photoresponse of these detectors is both statically tailorable and dynamically tunable by varying the n barrier layer thickness and applied bias, respectively. QE's of  $\sim 5\%$  at wavelengths ranging from  $8\text{--}12\text{ }\mu\text{m}$  have been obtained with  $-3\text{ V}$  bias at  $15\text{ K}$ .
- **Demonstrated** a new detector structure, the CHIP (Camel-barrier HIP) detector, by incorporating a Sb delta-doped layer between the p+ SiGe layer and p-Si substrate. In addition to the static spectral tailorability of the HIP detector, the CHIP detector offers an additional electrically tunable spectral response. The electrical spectral tunability offers important IR imaging system advantages such as real time target discrimination.
- **Fabricated** a novel JPL-invented infrared detector, the Layered Internal Photoemission Sensor (LIPS). At  $77\text{ K}$ , the dark current in these devices with guard rings was below the detection limit at a reverse bias of  $1\text{ V}$ . The LIPS device incorporates electrically floating epitaxial silicide particles embedded in single-crystal silicon, and responds in the  $1\text{--}2\text{ }\mu\text{m}$  regime. Detectivities of these devices have been measured at  $77\text{ K}$ , and are found to be as high as  $8 \times 10^9\text{ cm}^2/\text{Hz/W}$ .
- **Demonstrated** both low dark current and high responsivity at  $100\text{ }\mu\text{m}$  in a small germanium blocked impurity band (GeBIB) detector array.

### Nonlinear Optical Materials

- **Measured** large electro-optic  $r_{11}$  coefficient of dimethylamino stilbazolium tosylate (DAST) single crystal to be  $410\text{ pm/V}$  at  $820\text{ nm}$ , giving power figure of merit:  $n^3 r_{11}/\epsilon = 800\text{ pm/V}$  vs.  $11$  for  $\text{LiNbO}_3$ .
- **Measured** large second harmonic generation  $d_{11}$  coefficient of DAST single crystal to be  $620\text{ pm/V}$  at  $1907\text{ nm}$ .
- **Demonstrated**  $17\%$  electro-optic amplitude modulation up to  $100\text{ kHz}$  for an unoptimized DAST-based Pockels cell.
- **Demonstrated** strategy based on heavy atom effect and triplet-triplet absorption for enhancing nonlinear absorption in phthalocyanine dyes leading to threefold reduction in threshold of optical limiting device.

- **Demonstrated** phthalocyanine dye-based optical limiter device capable of protecting a silicon detector from 8-nanosecond duration laser pulses of energy over 300 times the normal damage threshold.
- **Demonstrated** strategy for enhanced optical limiting materials by distributing dyes with high nonlinear absorption in host media with large nonlinear refraction leading to improved clamped throughput characteristics approaching DoD requirements for eye protection.

### Fiber Optics

- **Demonstrated** ultra-fast (860-fs) pulse source (erbium fiber mode-locked fiber ring) at 1.55  $\mu\text{m}$  for driving optical protocols fiber network to 100 Gbit/s capacity.
- **Analyzed** LDEF space shuttle experiment results, which indicated that commercially jacketed fiber optics can survive five years in space if properly designed. Prolonged space exposure and thermal cycling was observed to cause tolerable stiffening of cable sheath, movement of fiber strains within the jacket, and variation of the fiber transmission efficiency with temperature.
- **Developed** multiple HIPPI supercomputer interface concept for 50 Gbit/s hot potato network.

### Photovoltaic Technology

- **Fabricated** diagnostic p-i-n solar cells incorporating ECR-deposited a-Si:H and a-SiC:H films. These diagnostic devices are being used to evaluate material properties for photovoltaic applications.
- **Developed** highly conductive p-type microcrystalline SiC:H films with a conductivity of  $0.2 \text{ (}\Omega\text{-cm)}^{-1}$  for window layer applications in p-i-n solar cells. The high conductivity of the window layer can increase the open circuit voltage of p-i-n solar cells.
- **Demonstrated** the magnetic field profile control on the ion density and energy in the ECR deposition process for achieving optimized material properties. ECR-deposited a-Si:H films have shown an optimized defect density of  $1\text{--}2 \times 10^{16} \text{ (cm}^{-3}\text{)}$  with the mirror magnetic field in the range of 300 to 800 Gauss.
- **Invented** a new a-Si(Xe,H) material, deposited by ECR plasmas using  $\text{SiH}_4$ , Xe and  $\text{H}_2$  gases, in which hydrogen bonded to silicon is lower than the detection limit of the infrared spectroscopy. Photodegradation studies of a-Si(Xe,H) films have shown improved stability for photovoltaic applications.

### **Space Environmental Effects on Materials**

- **Identified** the mechanism for the synergistic effect between VUV radiation and atomic oxygen in the degradation of space qualified materials.
- **Determined** the microscopic mechanism of the VUV degradation pathway in fluorinated polymers, including primary photoproducts and the efficiencies of these processes.
- **Demonstrated** the validity of ground based exposure methodology by direct comparison to space exposed samples recovered from LDEF.

## **Spatial Light Modulators**

### **Publications**

"Strong Photo-optic Effects in Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structures"

A. Larsson and J. Maserjian

OSA Topical Meeting on Optical Computing, Salt Lake City, UT, March 4–6, 1991

"Optically Induced Absorption Modulation in a Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structure"

A. Larsson and J. Maserjian

Appl. Phys. Lett., vol. 58, p. 1946 (1991)

"Low Power Optically-Addressed Spatial Light Modulators Using MBE-Grown III-V Structures"

J. Maserjian and A. Larsson

Proceedings of the SPIE Symposium, San Diego, CA, 22–26 July 1991, paper 1562–09 (in press)

"MBE-Engineered III-V Semiconductor Structures for Low Power Optically-Addressed Spatial Light Modulators"

A. Larsson and J. Maserjian

Optical Engineering (in press)

"Optically Induced Excitonic Electroabsorption in a Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structure"

A. Larsson and J. Maserjian

Appl. Phys. Lett. (accepted)

"An Optically Addressed Asymmetric Fabry-Perot Modulator"

A. Larsson and J. Maserjian

Appl. Phys. Lett. (accepted)

### **Invited Presentations**

"MBE Engineering of Novel Semiconductor Devices Using Abrupt Doping Profiles"

J. Maserjian

Gordon Research Conference on Crystal Growth, Plymouth, NH, July 15–19, 1991

"Low Power Optically-Addressed Spatial Light Modulators using MBE-Grown III-V Structures"

J. Maserjian and A. Larsson

SPIE Symposium, San Diego, CA, 22–26 July 1991

"MBE Engineered III-V Structures for Low Power Optically-Addressed Spatial Light Modulators"

J. Maserjian

Optical Sciences Colloquium, University of Arizona, Tucson, AZ, October 3, 1991

**"Spatial Light Modulators"**

J. Maserjian

JPL Conference on Optical Applications to Microwave and Millimeter-Wave Systems, JPL, Pasadena, CA, October 8, 1991

**"Quantum Well Optically-Addressed Spatial Light Modulators"**

J. Maserjian

SDIO Technology Applications Review, Albuquerque, NM, November 21, 1991

**Presentations**

**"Strong Photo-optic Effects in Periodically d-Doped InGaAs/GaAs Multiple Quantum Well Structures"**

A. Larsson and J. Maserjian

OSA Topical Meeting on Optical Computing, Salt Lake City, UT, March 4-6, 1991

**Patent and New Technology Reports**

**"Analog Optical Link for Focal-Plane Readout"**

E. Fossum, A.G. Larsson and J. Maserjian

New Tech. Report No. 18481/8019, February 6, 1991

**"MBE Engineered III-V Semiconductor Structures for Low Power Optically Addressed Spatial Light Modulators"**

A. Larsson and J. Maserjian

New Technology Report 18689/8244, September 23, 1991

**"Time-Multiplexed Optically-Addressed Gigabit Optical Crossbar Switch"**

R.J. Lang, J. Maserjian and L. Cheng

New Technology Report 18752/8317, December 18, 1991

**"All Optical Photochromic Spatial Light Modulators Based on Photoinduced Electron Transfer in Rigid Matrices"**

D.N. Beratan and J.W. Perry

U.S. Patent No. 5,062,693, November 5, 1991

**"Photovoltaic-Driven Quantum Well Modulator"**

J. Maserjian

U.S. Patent No. 4,953,955, September 4, 1990

## **Lasers**

### **Publications**

"High-power AlGaAs/GaAs Single Quantum Well Surface-Emitting Lasers with Integrated 45°-Beam-Deflectors"

J. Kim, R. Lang and A. Larsson (with TRW and Hughes)  
Appl. Phys. Lett., vol. 57, no. 20, p. 2048, November 12, 1990

"Electron-beam Lithography and Chemically Assisted Ion Beam Etching for the Fabrication of Grating Surface-emitting Broad-area AlGaAs Lasers"

R. J. Lang, A. Larsson, S. Forouhar and J. Cody (with Cornell Univ.)  
J. Vac. Sci. Technol. B, vol. 8, p. 1408, 1990

"Pseudomorphic InGaAs/GaAs/AlGaAs Single Quantum Well Surface-emitting Lasers with Integrated 45°-beam-deflectors"

J. Kim and A. Larsson (with TRW)  
Appl. Phys. Lett., vol. 58, no. 1, p. 7, 1991

"Lateral Modes of Broad Area InGaAs Lasers: Theory and Experiment"

R.J. Lang, A. Larsson, S. Forouhar and J. Cody  
IEEE Journal of Quantum Electronics (accepted)

"A New Geometric Formalism for Unstable Resonators"

R.J. Lang  
Optics Letters (accepted)

### **Presentations**

"Surface-emitting Single Quantum Well Lasers with Integrated Beam Deflectors"

J. Kim  
IEEE LEOS'90 Annual Meeting, Boston, MA, November 4-9, 1990

"Reliable Operation of High Power Density Ridge Waveguide Pseudomorphic Single Quantum Well Lasers at 980 nm"

S. Forouhar, A. Larsson, J. Cody and R.J. Lang  
IEEE LEOS'90 Annual Meeting, Boston, MA, November 4-9, 1990

"High Power Single Element Pseudomorphic InGaAs/GaAs/AlGaAs Single Quantum Well Lasers for Pumping Er-doped Fiber Amplifiers"

A. Larsson, S. Forouhar, J. Cody, R. Lang and P.A. Andrekson  
SPIE OE/LASE'91, Los Angeles, CA, January 1991

## Patent and New Technology Reports

"Self-collimating Unstable Resonator Diode Laser"

R.J. Lang

NASA Tech. Brief NPO-18386, October 15, 1990 (filed)

"Pseudomorphic  $\text{In}_x\text{Ga}_{1-x}\text{As}$  Surface Emitting Lasers for Optical Parallel Processing Applications"

J.H. Kim

NASA Tech. Brief NPO-18243, 1991 (filed)

" $\text{Al}_x\text{Ga}_{1-x}\text{As}$  Single Quantum Well Surface-Emitting Lasers"

J.H. Kim

NASA Tech. Brief NPO-18281, 1991 (filed)

"High-Power  $\text{AlGaAs}$  Quantum-Well Lasers on Si Substrates"

J.H. Kim, R.J. Lang, G. Radhakrishnan and J. Katz

NASA Tech. Brief NPO-17988, vol. 15, no. 9, p. 26, September 1991

"Two-Period Gratings for Surface Emitting Laser"

R. Lang

NASA Tech. Brief NPO-18054, vol. 15, no. 12, p. 26, December 1991

"Laterally Coupled Distributed Feedback Laser"

R.J. Lang and S. Forouhar

NASA Tech. Brief NPO-18393, vol 16, no. 4, p. 24, April 1992

"Annular Bragg Grating Surface-emitting Laser" & "Two-period Gratings for Surface-emitting Lasers"

R.J. Lang

A patent is being prepared combining two Technology disclosures, NASA Tech. Brief NPO-18054, vol. 15, no. 12, p. 26, December 1991 and NASA Tech. Brief NPO-17192 vol 12, no. 11, p. 34, December 1988

"Self-collimated Unstable Resonator Diode Laser"

R.J. Lang

Patent Application, NPO-018386, August 28, 1991 (filed)

"Two-Period Gratings for Surface Emitting Laser"

R. Lang

Patent Application, 782,009, October 21, 1991 (filed)

## **Optoelectronic Materials and Characterization**

### **Publications**

"Strong Photo-optic Effects in Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structures"

A. Larsson and J. Maserjian

Proceedings of the OSA Topical Meeting on Optical Computing, Salt Lake City, UT, March 4-6, 1991

"Optically Induced Absorption Modulation in a Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structure"

A. Larsson and J. Maserjian

Appl. Phys. Lett., vol. 58, p. 1946, 1991

"Photon Assisted Resonant Tunneling Through Variably Spaced Superlattice Energy Filters"

A. Larsson, S.I. Borenstain, B. Jonsson, I. Andersson, J. Westin and T.G. Andersson

Applied Physics Letters (accepted)

### **Invited Presentations**

"Optically Induced Absorption Modulation in a Periodically  $\delta$ -doped InGaAs/GaAs Multiple Quantum Well Structures"

J. Maserjian and A. Larsson

Workshop on Optical Properties of Mesoscopic Semiconductor Structures, Snowbird, UT, April 23-26, 1991

"MBE Engineering of Novel Semiconductor Devices Using Abrupt Doping Profiles"

J. Maserjian

Gordon Research Conference on Crystal Growth, Plymouth, NH, July 15-19, 1991

### **Presentations**

"Strong Photo-optic Effects in Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structures"

A. Larsson and J. Maserjian

Late News Paper at OSA Topical Meeting on Optical Computing, Salt Lake City, UT, March 4-6, 1991

"Strong Photo-Optic Effects in Periodically  $\delta$ -Doped InGaAs/GaAs Multiple Quantum Well Structures"

A. Larsson and J. Maserjian

IEEE/LEOS Quantum Optoelectronics Meeting, Salt Lake City, UT, March 11-13, 1991

## **Optoelectronic Integrated Circuits**

### **Publications**

"Monolithically Integrated Optoelectronic Thresholding Device for Neural Network Applications"

S. Lin, F. Ho, J. Kim and D. Psaltis

Proceedings of the OSA CLEO'91, Baltimore, MD, May 12-17, 1991

### **Invited Presentations**

"Optoelectronic Master Chip for Optical Computing"

R.J. Lang

SPiE Symposium, San Diego, CA, July 22, 1991

### **Presentations**

"GaAs-based Optoelectronic Neurons"

S. Lin and J. Kim (with Caltech)

IEEE LEOS and OSA Topical Meeting on Optical Computing and Photonic Switching, Salt Lake City, UT, March 4-8, 1991

"High-gain GaAs Optoelectronic Thresholding Devices for Neural Network Implementation"

S. Lin and J. Kim (with Caltech)

IEEE LEOS Integrated Photonics Research Topical Meeting, Monterey, CA, April 9-11, 1991

"Monolithically Integrated Optoelectronic Thresholding Device for Neural Network Applications"

S. Lin, F. Ho, J. Kim and D. Psaltis

OSA CLEO'91, Baltimore, MD, May 12-17, 1991

### **Patent and New Technology Reports**

"GaAs-based Optoelectronic Neurons"

S.H. Lin, J.H. Kim and D. Psaltis

NASA Tech. Brief NPO-18497, February 27, 1991 (filed)

## **Infrared Detectors**

### **Publications**

"A Novel Si-based LWIR Detector: The SiGe/Si Heterojunction Internal Photoemission Detector"

T.L. Lin, E.W. Jones, A. Ksendzov, S.M. Dejewski, R.W. Fathauer, T.N. Krabach, J. Maserjian

The International Electron Device Meeting Technical Digest, vol. 641, 1990

"Infrared Response from Metallic Particles Embedded in a Single-crystal Si Matrix: the Layered Internal Photoemission Sensor"

R.W. Fathauer, J.M. Iannelli, C.W. Nieh and S. Hashimoto

Applied Physics Letters, vol. 57, p. 1419, 1990

"Novel  $p^+-Si_{1-x}Ge_x/p$ -Si Heterojunction Detectors Fabricated by Molecular Beam Epitaxy"

T.L. Lin and J. Maserjian

Applied Physics Letters, vol. 57, p. 1442, 1990

"Advanced Si IR Detectors Using Molecular Beam Epitaxy"

T.L. Lin, E. W. Jones, T. George, A. Ksendzov and M.L. Huberman

Proceedings of the 1991 SPIE Symposium, July 1991

"Long-Wavelength Infrared Detectors Based on III-V Materials"

J. Maserjian

Proceedings of the 1991 SPIE Symposium, July 1991

"Silicon-based Long Wavelength Infrared Detectors Fabricated by Molecular Beam Epitaxy"

T.L. Lin, E. W. Jones, T. George, A. Ksendzov and M.L. Huberman

Mat. Res. Soc. Symp. Proc., vol. 220, p. 477, 1991

"SiGe/Si Heterojunction Internal Photoemission Long Wavelength Infrared Detectors Fabricated by Molecular Beam Epitaxy"

T.L. Lin, A. Ksendzov, S.M. Dejewski, E.W. Jones, R.W. Fathauer, T.N. Krabach, J. Maserjian

IEEE Trans. Electron Devices, vol. ED-38, p. 1145, 1991

### **Invited Presentations**

"Si-compatible Sensor Development Ongoing in the Sensor Technology Group"

R. Fathauer

Texas Instruments Central Research Laboratory, October 5, 1990

"The SiGe/Si Heterojunction Internal Photoemission Sensor"

R. Fathauer and T.L. Lin.

Briefing given at SDI Passive Sensor Technology Program review, Naval Ocean Systems Center in San Diego, CA, January 31, 1991

"Long Wavelength Infrared Detector Research Based on III-V and IV Semiconductors"  
J. Maserjian  
University of California, Berkeley, CA, March 6, 1991

"Long Wavelength Infrared Detector Research Based on III-V and IV Semiconductors"  
J. Maserjian  
University of California State University, Los Angeles, CA, May 29, 1991

"Long-Wave Infrared Detectors Based on IV and III-V Materials"  
J. Maserjian  
Semiconductor Superlattice Materials and Applications Workshop, Hughes Research  
Laboratory, Malibu, CA, July 3, 1991

"Long-Wavelength Infrared Detectors Based on III-V Materials"  
J. Maserjian  
SPIE Symposium, San Diego, CA, July 22-26, 1991

"Advanced Si-based LWIR Detectors by Molecular Beam Epitaxy"  
T.L. Lin  
SPIE Symposium, San Diego, CA, July 22-26, 1991

"Growth and Properties of Novel Silicide/Silicon Heterostructures"  
R. Fathauer  
Rensselaer Polytechnic Institute, November 1991

"Recent Results on the Si/SiGe Heterojunction Internal Photoemission LWIR Detector"  
R. Fathauer  
Rome Air Development Center, November 10, 1991

"Recent Results on the Si/SiGe Heterojunction Internal Photoemission LWIR Detector"  
R. Fathauer  
MIT Lincoln Labs, November 11, 1991

"SiGe/Si Heterojunction Internal Photoemission Detectors"  
T.L. Lin  
Rome Laboratory, Boston, MA, December 5, 1991

"SiGe/Si Heterojunction Internal Photoemission Detectors"  
T.L. Lin  
MIT Lincoln Laboratory, Boston, MA, December 6, 1991

"SiGe/Si Heterojunction Internal Photoemission Detectors"  
T.L. Lin  
Naval Research Laboratory, Washington, DC, December 12, 1991

"SiGe/Si Heterojunction Internal Photoemission Detectors"  
T.L. Lin  
David Sarnoff Research Center, Princeton, NJ, December 13, 1991

## **Presentations**

"SiGe/Si Heterojunction Internal Photoemission Long-wavelength Infrared Detectors"

R. Fathauer (for T. Lin)

1990 Fall Materials Research Society Meeting, Boston, MA, November 26–30, 1990

"Novel Infrared Detectors Based on Three-dimensional Schottky Barrier Structures"

R. Fathauer

1990 Fall Materials Research Society Meeting, Boston, MA, November 26–30, 1990

"A Novel Si-based LWIR Detector: The SiGe/Si Heterojunction Internal Photoemission Detector"

T.L. Lin, E.W. Jones, A. Ksendzov S.M. Dejewski, R.W. Fathauer, T.N. Krabach and J. Maserjian

International Electron Device Meeting, San Francisco, CA, December 9–12, 1990

"Silicon-based Long Wavelength Infrared Detectors Fabricated by Molecular Beam Epitaxy"

T.L. Lin

1991 Spring Material Research Society Symposium, Anaheim, CA, April 29–May 3, 1991

"SiGe/Si Camel-barrier Heterojunction Internal Photoemission LWIR Detector,"

T.L. Lin

1991 Device Research Conference, Boulder, CO, June 17–19, 1991

"The Si/SiGe Heterojunction Internal Photoemission Sensor; Optimization of Materials and Device Parameters "

R.W. Fathauer, T.L. Lin, M.L. Huberman, S.M. Dejewski, T.N. Krabach and J. Maserjian  
1991 Meeting of IRIS Specialty Group on Infrared Detectors, NIST, Boulder, CO, August 13–16, 1991

"Novel SiGe/Si Infrared Detector Grown by Molecular Beam Epitaxy"

T.L. Lin, A. Ksendzov, T.N. Krabach, J. Maserjian, M.L. Huberman and R. Terhune  
AVS Meeting, Toronto, Canada, October 8–12, 1991

## **Patent and New Technology Reports**

"Low-Power Analog Optical Link for Focal-Plane Readout"

E. Fossum and A.G. Larsson and J. Maserjian

New Technology Report NPO-30-18481, January 28, 1991 (filed)

"Laterally Stacked Schottky Diodes for Infrared Sensor Applications"

T.L. Lin

New Technology Report NPO-17426, October 8, 1987 (filed)

"Formation of Self-aligned Guard Rings for Monolithic Schottky-barrier Diode Arrays"

T.L. Lin

NASA Tech. Brief NPO-17734, vol. 14, no. 8, p. 20, August 1990

"Optical Link for Readout from Focal-Plane Array"

E.R. Fossum, A.G. Larsson and J. Maserjian

NASA Tech. Brief NPO-18481, February 28, 1991 (filed)

"Phototransistors for Long-Wavelength Infrared"

S. Borenstain,

NASA Tech. Brief, NPO-18029, vol. 15, no. 5, p. 26, May 1991

"Ir/IrSi<sub>3</sub>/Si Schottky-Barrier Infrared Detector"

T.L. Lin

NASA Tech. Brief, vol. 15, no. 10, p. 22, October 1991

"SiGe/Si Infrared Photodiodes"

T.L. Lin

NASA Tech. Brief, vol. 15, no. 10, p. 26, October 1991

"InAs HIDS LWIR Detector"

J. Maserjian

Patent Application Case No. NPO-17880, vol. 15, no. 9, p. 22, September 1991

"Laterally Stacked Schottky Diodes for Infrared Sensor Applications"

T.L. Lin

U.S. Patent No. 4,990,988, February 5, 1991

## Nonlinear Optical Materials

### Publications

"Materials for Nonlinear Optics: Chemical: Perspectives"

S.R. Marder, J.E. Sohn and G.D. Stucky, eds.

ACS Symp. Ser., vol. 455, American Chemical Society, Washington, DC, 1991

"Second-Order Optical Nonlinearities and Photostabilities of 2-N-Methyl Stilbazolium Salts"

S.R. Marder, J.W. Perry, B.G. Tiemann, R.E. Marsh and W.P. Schaefer

Chemistry of Materials, vol. 2, 685, 1990

"Molecular and Macroscopic Second-Order Nonlinear Optical Properties of Dinitrostilbenes and Related Compounds. Chemistry of Materials"

B.G. Tiemann, S.R. Marder, J.W. Perry and L.T. Cheng

Chemistry of Materials, vol. 2, 690, 1990

"New Polymeric Materials with Cubic Optical Nonlinearities Derived From Ring-Opening Metathesis Polymerization of Substituted Cyclooctatetraenes"

R.H. Grubbs, C.B. Gorman, E.J. Ginsburg, J.W. Perry and S.R. Marder

In, Materials for Nonlinear Optics: Chemical: Perspectives, ACS Symp. Ser., vol. 455, S.R. Marder, J.E. Sohn, G.D. Stucky, eds., American Chemical Society, Washington, DC, p. 672, 1991

"Linear and Nonlinear Polarizability: A Primer"

G.D. Stucky, S.R. Marder and J.E. Sohn

In, Materials for Nonlinear Optics: Chemical: Perspectives, ACS Symp. Ser., vol. 455, S.R. Marder, J.E. Sohn, G.D. Stucky, eds., American Chemical Society, Washington, DC, p. 2, 1991

"Nonlinear Optical Properties of Molecules and Materials"

J.W. Perry

In, Materials for Nonlinear Optics: Chemical: Perspectives, ACS Symp. Ser., vol. 455, S.R. Marder, J.E. Sohn, G.D. Stucky, eds., American Chemical Society, Washington, DC, p. 2, 1991

"Second-Order Molecular and Macroscopic Optical Nonlinearities of Organic and Organometallic Compounds"

S.R. Marder, B.G. Tiemann, J.W. Perry, L.T. Cheng, W. Tam, W.P. Schaefer and R.E. Marsh

In, Materials for Nonlinear Optics: Chemical: Perspectives, ACS Symp. Ser., vol. 455, S.R. Marder, J.E. Sohn, G.D. Stucky, eds., American Chemical Society, Washington, DC, p. 187, 1991

"Second-Order Optical Nonlinearities and Crystal Structure and of 2-Methoxy- 4' Nitro-(E)Stilbene"

R.B. Grubbs, S.R. Marder, J.W. Perry and W.P. Schaefer

Chemistry of Materials, vol. 3, 3, 1991

"Approaches for Optimizing the First Electronic Hyperpolarizability of Conjugated Organic Molecules"

S.R. Marder, D.N. Beratan and L.T. Cheng  
Science, vol. 255, 103, 1991

"Excited State Absorption and Optical Limiting in Solutions of Metallophthalocyanines"

J.W. Perry, L.R. Khundkar, D.R. Coulter, D. Alvarez, Jr., S.R. Marder, T.H. Wei, M.J. Sence, E.W. Van Stryland and D.J. Hagan  
In, Proceedings of 1990 NATO Workshop of Hyperpolarizabilities of Organic Compounds. Kluwer Academic Publishers, NY, p. 369, 1991

"Organometallic Salts with Large Second-Order Optical Nonlinearities: (E) -{1-ferrocenyl-2-(4-N-methyl pyridinium)ethylene)} Salts"

S.R. Marder, J.W. Perry, W.P. Schaefer and B.G. Tiemann  
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"Nonlinear Optical Hyperpolarizabilities of Ferrocenyl and Ruthenacenyl Complexes"

J.C. Calabrese, L.T. Cheng, J.C. Green, S.R. Marder and W. Tam  
J. Amer. Chem. Soc., vol. 113, 7227, 1991

"The Electronic Structure and Second-Order Nonlinear Optical Properties of Donor-Acceptor Substituted Acetylenes: A Detailed Investigation of Structure-Property Relationships"

A.E. Stiegman, E. Graham, K.J. Perry, L.R. Khundkar, L.T. Cheng and J.W. Perry  
J. Amer. Chem. Soc., vol. 113, 7658, 1991

"Substituted Polyacetylenes through the Ring-Opening Metathesis Polymerization (ROMP) of Substituted Cyclooctatetraenes: a Route into Soluble Polyacetylenes"

C.B. Gorman, E.J. Ginsburg, M.J. Sailor, J.S. Moore, T.H. Jozefiak, S.R. Marder, J.W. Perry, N.S. Lewis and R.H. Grubbs  
Synth. Met., vol. 41, p. 1033, 1991

"Second-Order Nonlinear Optical Properties of 4-N-Methylstilbazolium Tosylate Salts"

C.P. Yakymyshyn, S.R. Marder, K.R. Stewart, E.P. Boden, J.W. Perry and W.P. Schaefer  
Proceedings of the International Conference on Organic Materials for Nonlinear Optics II, Royal Society of Chemistry Special Publication #91, R.A. Hann, D. Bloor, eds., Royal Society of Chemistry, Cambridge, England, p. 108, 1991

"Structure/Property Relationships for Organic and Organometallic Materials with Second-Order Optical Nonlinearities"

S.R. Marder, D.N. Beratan, B.T. Tiemann, L.T. Cheng and L.T. Tam  
Proceedings of the International Conference on Organic Materials for Nonlinear Optics II, Royal Society of Chemistry Special Publication #91, R.A. Hann and D. Bloor, eds., Royal Society of Chemistry, Cambridge, England, p. 165, 1991

"Direct Measurements of Nonlinear Absorption and Refraction in Solutions of Phthalocyanines"

T.H. Wei, D.J. Hagan, M.J. Sence, E.W. Van Stryland, J.W. Perry and D.R. Coulter  
Appl. Phys. B., vol. 53, 1991 (in press)

"Structure/Property Relationships for Molecular Second-order Nonlinear Optics"  
S.R. Marder, L.T. Cheng, B.G. Tiemann and D.N. Beratan  
Proc. SPIE, vol. 1560, 1991 (in press)

"Organic Salts with Large Electro-optic Coefficients"  
J.W. Perry, S.R. Marder, K.J. Perry, E.T. Sleva, C. Yakymyshyn, K.R. Stewart and  
E.P. Boden  
Proc. SPIE, vol. 1560, 1991 (in press)

"Experimental Investigation of Organic Molecular Nonlinear Optical Polarizabilities 1.  
Methods and Results on Benzene and Stilbene Derivatives"  
L.T. Cheng, W. Tam, S.H. Stevenson, G.R. Meredith, G. Rikken and S.R. Marder  
J. Phys. Chem., 1991 (accepted)

"Experimental Investigation of Organic Molecular Nonlinear Optical Polarizabilities 2.  
Effects of Conjugation"  
L.T. Cheng, W. Tam, S.R. Marder, A.E. Stiegman, G. Rikken and C.W. Spangler  
J. Phys. Chem., 1991 (accepted)

"An Organometallic Cyanine: Bis[ $\mu^2$ -Carbonyl-dicarbonyl-bis( $\eta^5$ -cyclopentadienyl)]di-  
iron]  $\mu$ -1,3,5-heptatriene tetra-fluoroborate"  
W.P. Schaefer, J.M. Spotts and S.R. Marder  
Acta Cryst. C., 1991 (accepted)

### **Invited Presentations**

"Nonlinear Optical Devices Using Organic Materials"  
J.W. Perry  
American Chemical Society National Meeting, NY, August 25–30, 1991

"Nonlinear Optical Devices Using Organic Materials"  
J.W. Perry  
California State University, Northridge, Dept. of Chemistry Seminar, November 1991

"Nanosecond Optical Switching: Optical Limiters Based on Reverse Saturable Absorption  
in Macrocyclic Dye Complexes"  
J.W. Perry  
Third Annual Review of the U.S. Army Advanced Laser Protection Program, Washington,  
DC, October 1991

"Optical Limiters Based on Excited State Absorption in Macrocyclic Dye Complexes"  
J.W. Perry  
Hughes Research Laboratories, Malibu, CA, December 1991

"Design of Nonlinear Optical Materials"  
D.N. Beratan, L.T. Cheng, S.R. Marder, J. Murdoch, J.W. Perry, B.G. Tiemann,  
J.C.C. Tseng and G. Van Doremaele  
Society American Chemical Society National Meeting, NY, August 25–30, 1991

"Optimizing the Second-order Optical Nonlinearities of Organic Molecules"

S.R. Marder, D.N. Beratan, L.T. Cheng and B.G. Tiemann

Society for Photooptical and Instrumentation Engineers National Meeting, San Diego, CA,  
July 22–26, 1991

### **Presentations**

"Optimizing the Second-Order Optical Nonlinearities of Organic Molecules"

S.R. Marder, D.N. Beratan, L.T. Cheng and B.G. Tiemann

American Chemical Society National Meeting, Atlanta, GA, April, 14–19, 1991

"Second-Order Nonlinear Optical Properties of 4-N-Methylstilbazolium Tosylate Salts"

C.P. Yakymyshyn, S.R. Marder, K.R. Stewart, E.P. Boden, J.W. Perry and W.P. Schaefer  
Conference on Laser and Electrooptics, Baltimore, MD, May, 12–17, 1991

"Organic Salts with Large Electro-optic Coefficients"

J.W. Perry, S.R. Marder, K.J. Perry, E.T. Sleva, C.P. Yakymyshyn, K.R. Stewart and E.P. Boden

Society for Photooptical and Instrumentation Engineers National Meeting, San Diego, CA,  
July 22–26, 1991

"The Synthesis and Spectroscopic Properties of Organometallic Cyanines"

J. M. Spotts, W. P. Schaefer and S.R. Marder

American Chemical Society National Meeting, NY, August 25–30, 1991

"Nonlinear Optical Properties of Phthalocyanines"

D. Alvarez, G. Cummings, S.R. Marder, J.W. Perr and K.J. Perry

American Chemical Society National Meeting, NY, August 25–30, 1991

### **Patent and New Technology Reports**

"Organometallic Salts Generate Second Harmonics"

S.R. Marder and J.W. Perry

NASA Tech. Brief NPO-17730, vol. 15, no. 6, p. 54, June 1991

"Electrooptic Polymer Voltage Sensor and Method of Manufacture Thereof"

J.W. Perry and A. Gottsche

NASA Tech Briefs NPO-18207, March, 8, 1990, and NPO-18311 February 19, 1990  
(submitted, patent pending)

## **Fiber Optics**

### **Publications**

"Optical Protocols for Terabit Networks"

P.L. Chua, J.L. Lambert, J.M. Morookian and L.A. Bergman

American Institute of Aeronautics and Astronautics, Proceedings Baltimore, MD, October 1991

### **Invited Presentations**

"Optical Networks: Components and Architectures for Overcoming the Electronic Bottleneck"

L.A. Bergman

DARPA Optoelectronics Workshop, Washington, DC, January 31–February 1, 1991

"Optical Protocols for Terabit Networks"

L.A. Bergman

DARPA PI Workshop, Monterey, CA, March 28, 1991

"LDEF Fiber Optic Exposure Experiment"

A. Johnston, L. Bergman and R. Hartmayer

First LDEF Post-Retrieval Symposium, Kissimmee, FL, June 2–8, 1991

"Optical Protocols for Advanced Spacecraft Networks"

L.A. Bergman

NASA Space Station Evolution Conference, Houston, TX, August 7, 1991

"Optical Protocols for Terabit Networks"

P.L. Chua, J.L. Lambert, J.M. Morookian and L.A. Bergman

AIAA Conference, Baltimore, MD, October 23, 1991

"Advanced Networks: Application of IS&T Technology for Multi-Gigabit Networks"

L. A. Bergman

IS&T Workshop on Nanostructures and Applications, Tucson, AZ, November 19, 1991

## **Photovoltaic Technology**

### **Publications**

"Electron Cyclotron Resonance Microwave Plasma Deposition of a-Si:H and a-SiC:H Films"

Y.H. Shing and F.S. Pool  
Solar Cells, 30, 391, 1991

"Characterization of Electron Cyclotron Resonance Plasma-Deposited Hydrogenated Amorphous Silicon and Related Alloy Films"

J.M. Essick, F.S. Pool, Y.H. Shing and M.J. Holboke  
Mat. Res. Soc. Symp. Proc., 679, 1991

"Deposition Dependence of the Deep Defect Density for a-Si:H Grown by Electron Cyclotron Resonance Microwave Plasma"

J.M. Essick, F.S. Pool and Y.H. Shing  
J. Vac. Science and Technology (accepted)

"Material Properties and Device Evaluations of ECR-Deposited a-Si:H and a-SiC:H Films"

Y.H. Shing, F.S. Pool and J.M. Essick  
22nd IEEE Photovoltaic Specialists Conference Proceedings, 1991 (in press)

"Electron Cyclotron Resonance Deposition of Amorphous Silicon Alloy Films and Devices"

Y.H. Shing, F.S. Pool and J. M. Essick  
National Renewable Energy Laboratory Photovoltaic Branch Annual Report (accepted)

### **Presentations**

"Material Properties and Device Evaluations of ECR-Deposited a-Si:H and a-SiC:H Films"

Y.H. Shing, F.S. Pool and J.M. Essick  
22nd IEEE Photovoltaic Specialists Conference, Las Vegas, NV, October 7-11, 1991

"Microcrystalline and Amorphous Silicon and Silicon Carbon Alloy Films Deposited by Microwave Plasmas"

Y.H. Shing and F. S. Pool  
5th International Photovoltaic Science and Engineering Conference, Kyoto, Japan, November 25, 1990

"Characterization of Electron Cyclotron Resonance Plasma-Deposited Hydrogenated Amorphous Silicon and Related Alloy Films"

J.M. Essick, F.S. Pool, Y.H. Shing and M.J. Holboke  
Materials Research Society, Anaheim, CA, April 29-May 3, 1991

## **Optical Signal Processing**

### **Publications**

"Superfine Resolution Acousto-Optic Spectrum Analysis"

H. Ansari and J.R. Lesh

Applied Optics, vol. 30, no. 11, pp. 1396-1400, April 10, 1991

### **Patent and New Technology Reports**

"Two-Dimensional Acousto-Optic Spectrum Analysis"

H. Ansari, B.D. Metscher and J.R. Lesh

NASA Tech. Brief NPO-18092, September 1991

"Superfine Resolution and Three-Dimensional Acousto-Optic Spectrum Analysis"

H. Ansari and J.R. Lesh

NASA Tech. Brief NPO-18122, September 1991

"Eliminating Bias in Acousto-Optic Spectrum Analysis"

H. Ansari and J.R. Lesh

NASA Tech. Brief NPO-18275, May 23, 1990 (filed)

## **Space Environmental Effects on Materials**

### **Publications**

"An Investigation of the Degradation of Fluorinated Ethylene Propylene (FEP) Copolymer Thermal Blanketing Materials Aboard LDEF and in the Laboratory"

A.E. Stiegman, D.E. Brinza, M.S. Anderson, T.K. Minton, E.G. Laue and R.H. Liang  
JPL Publication 91-10, May 15, 1991

"Vacuum-Ultraviolet Radiation/Atomic Oxygen Synergism in FEP Teflon Erosion"

A.E. Stiegman, D.E. Brinza, E.G. Laue, M.S. Anderson and R.H. Liang  
J. Spacecraft and Rockets (in press, 1991)

"VUV-Induced Degradation of FEP Teflon Aboard LDEF"

D. Brinza, A.E. Stiegman and R. Liang  
Proceedings of the First LDEF Post Retrieval Symposium, Orlando, FL, June 2-8, 1991 (in press)

### **Presentations**

"Characterization of Space and Ground Degradation of FEP"

D. Brinza, A.E. Stiegman and R. Liang  
AEROMAT 91 Meeting, ASM International, Long Beach, CA, May 20-24, 1991

"VUV-Induced Degradation of FEP Teflon Aboard LDEF"

D. Brinza, A.E. Stiegman and R. Liang  
First LDEF Post Retrieval Symposium, Orlando, FL, June 2-8, 1991



### III. Advanced Computing

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## Overview

Advanced concepts in hardware, software and algorithms are being pursued for application in next generation space computers and for ground-based analysis of space data. The research program focuses on massively parallel computation and neural networks, as well as optical processing and optical networking, which are discussed in the Photonics Section. Also included are theoretical programs in neural and nonlinear science, and device development for magnetic and ferroelectric memories.

## 1991 Major Technical Achievements

### Parallel Computation

- **Demonstrated** first concurrent implementation of CASA CALCRUST application between JPL and SDSC Cray YMP supercomputers.
- **Developed** 3D Parallel Electromagnetic Finite Element code for scattering analysis of arbitrarily shaped, inhomogeneous objects.
- **Ported** Parallel Electromagnetic Integral Equation code to the Intel Touchstone Delta system; ran cases as large as 30,000 (i.e., dense double precision complex matrix) unknowns.
- **Implemented** dynamic load balancing in 2D Electrostatic Particle-in-Cell (PIC) Code for Multiple Instruction Multiple-Data (MIMD) computers
- **Developed** instrumental line shape algorithm for broadband anisotropic radiation.
- **Developed** Multiple-Instruction Multiple-Data (MIMD) high performance computing testbed at JPL for the development of NASA Grand Challenge Earth and Space Science applications.
- **Initiated** system software and user tools, numerical algorithm development support for HPCC Earth and Space Science applications developers.
- **Implemented** the user interface and operating system environment on the Biological Information Signal Processor (BISP) system.
- **Demonstrated** the "Dynamic Load Balancing Algorithm" for the Time Warp Operating System (TWOS), which is the only parallel processing operating system that has the capability to move processes from one node to another during execution of a program on a parallel processor.
- **Demonstrated** the "Concurrent Theater Level Simulation" using TWOS. The only known wargame to provide a capability for enemy forces to attack from any direction and to engulf opposing forces. The simulation uses a road network that allows movement in any direction — it is not constrained to hex game type movements or to a piston type operation. In addition the model is data driven and allows changing locale and military force structure and doctrine easily without a need to recode the simulation.

- **Designed and implemented** the ray-identification algorithm for the three-dimensional perspective rendering. The algorithm runs efficiently on both sequential and parallel machines, including Sun Sparcstations, JPL MarkIIIfp, Intel iPSC/860 and the Intel Touchstone DELTA System.
- **Made** further developments on the analytic model of the Event Horizon for simulation. This directly applies to the recent parallel simulation synchronization algorithm developed last year called "Breathing Time Buckets". This theory has further applications in the field of parallel and sequential simulation.
- **Developed** the interactive features for the Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES). SPEEDES is a parallel simulation environment that supports multiple synchronization protocols transparently to the application. It now features some new state-of-the-art approaches for supporting interactive simulations.
- **Developed** a new version of the Time Warp synchronization algorithm to operate in the SPEEDES multi-synchronization environment. This means that all applications written under the SPEEDES environment can select Time Warp in addition to other synchronization protocols for parallel synchronization. Because SPEEDES uses incremental state saving techniques, the memory overhead for state saving in Time Warp is kept down to a minimum.
- **Developed** a new algorithm for performing proximity detection for parallel simulations called "The Distribution List". This algorithm, in a scalable way, solves the problem of "who can see who," which is fundamental to all military simulations on parallel computers.

### Neural and Analog Computing

- **Designed, fabricated, and demonstrated** for the first time fully parallel, programmable, synaptic array (VLSI) chips with analog weight resolution exceeding 12 bits (1 part in 4000), incorporated in a reconfigurable neural network hardware system. Configurable as both feedback and feed forward architectures, this hardware is based on vertical (parallel) stacking of 7-bit MDAC synapses and nonlinear (sigmoid) variable gain neuron chips. Convergence time of less than only a few microseconds has been demonstrated on this reconfigurable hardware. This translates into a computing speed of multibillion operations per second.
- **Developed and implemented** in hardware the new powerful "cascade backpropagation" algorithm for efficient supervised learning in feed forward neural network architectures. The neuron-synapse composite chip-based, reconfigurable neural network hardware system has been used to implement the new cascade backprop learning algorithm with "hardware-in-the-loop" for the first time. A separate graphics routine developed for the purpose allows a real time display of the network architecture and its performance during learning of the ill-defined transformations as well as during the mapping exercises.

- **Demonstrated** a sonar signature discrimination problem (Navy) and a Landsat imagery interpretation problem (Army) as examples of ill-defined transformations captured by the learning capabilities of the neural networks in hardware. The ill-defined nature of these problems makes it extremely difficult to solve them using conventional computing techniques.
- **Expanded** our optical neuron array chip to include 4096 neurons (64 x 64 array, based on phototransistors) for thresholding and winner take all functions, fabricated in 2 micron CMOS. The chip, designed primarily for correlation peak detection function in the neocognitron architecture, provides a factor of 4 enhancement in the resolution of the peak detection compared to the earlier 32 x 32 photodetector array chip.
- **Developed and demonstrated** for the first time a dedicated processor chip for route planning. Given mobility costs per pixel over a terrain of interest, the 24 x 25 pixel-processor array chip based on a highly parallel architecture, computes all possible paths from a selected (origin) pixel in parallel, providing orders of magnitude speed enhancement compared to a typical sequential computer. The chip has direct applications in planetary rover navigation, robotics, and battlefield management. The path planner chip, interfaced with a PC, can compute and display, for example, simultaneous advances of "red" and "blue" teams on any constrained terrain, isocost contours for the different movers, as well as the best path to reach virtually any point on the terrain, with an estimate of the required cost.
- **Demonstrated** for the first time a high-speed non-destructive photoresponse readout from optically addressed ferroelectric lead zirconate titanate (PZT) thin film memory elements. When illuminated with laser pulses as short as ~ 25 nsec, the short circuit photocurrent from the PZT samples represents nondestructive readout of the information, stored in a nonvolatile fashion as remanent polarization in the thin film memory elements. Furthermore, the readout signal or the remanent polarization exhibited negligible degradation even after over a million readouts.
- **Successfully transferred** selected neural network hardware **technology** (VLSI designs and implementation know-how) to a U.S. industry (McDonnell Douglas) and a national laboratory (C. S. Draper Laboratory). The technology transfer activities with the two organizations have resulted in board level neural network hardware products, primarily optimized for the applications selected by the respective organizations. These hardware products represent some of the very first such high speed, artificial neural networks, tailored for specific functions.
- **Demonstrated** a new Boltzmann machine architecture that determines great circle arcs using certain associational data sent by an already existing tracker.

### Neurocomputing Theory and Nonlinear Science

- **Discovered** new method for global optimization of multiextremal functions based on "Terminal Repeller Unconstrained Subenergy Tunneling" (TRUST).

Over 100 times faster than competing state-of-the-art approaches on standard SIAM benchmarks

- TRUST algorithms designed for easy implementation on massively parallel optoelectronic hardware
  - Major benefit expected for many defense, space, and energy applications
- **Developed** new methodology for multitarget tracking in a dense threat environment based upon hydrodynamical techniques coupled with neural network algorithms.
  - Demonstrated tracking errors of under one percent for threat configurations involving several thousand elements
  - Method selected for priority classified dissemination by SDIO/IDA's Advanced Concepts Panel
- **Developed and demonstrated** an unipolar terminal-attractor based associative memory (UTABAM) system via adaptive threshold enabling perfectly correct convergence in the associative recall of inputs where the number of stored states are comparable to the number of neurons thus showing a significant improvement over the Hopfield neural net.
- **Discovered** a new pyramidal multi-layer multi-resolution optoelectronic data classification system utilizing the perfectly convergent unipolar terminal-attractor based associative memory and the futuristic SEED devices.
- **Developed** a new class of brain-in-a-cube-type bifurcating opto-electronic pattern recognition (BOPAR) technique for data classification using high-gain nonlinear photorefractive crystals with an experimental demonstration using barium titanite.
- **Developed** a new class of shift, rotation, and scale invariant adaptive optical pattern recognition (AOPAR) system for discerning a very faint object merged in a highly cluttered background and experimentally demonstrated using a high-gain photorefractive barium-titanite crystals.
- **Developed** the novel theory of Non-Lipschitzian Neural Dynamics.
  - The ability of our networks to change spontaneously their structural behavior as a result of parametrical periodic excitations lead to a performance that phenomenologically resembles brain activity
  - Work importance emphasized by biologists in recent issues of Journal of Neuroscience
  - Work also leads to design of unpredictable systems having important defense applications
- **Formulated** neural learning theory in terms of adjoint operators.
  - Enables highly efficient spatio-temporal pattern processing (order  $N^2$  speed up)
  - Designed for real-time applications

- **Developed** a new methodology enabling rapid tactical situation assessment under battlefield conditions.
  - Capable of identifying enemy force structures using as little as twenty percent of detected nodes and arbitrary template warping
  - Capable of predicting location of undetected nodes
- **Developed** methodology enabling the solution of partial differential equations on synchronous neural hardware. When implemented on novel CCD/CID chip (256 neurons, 65536 synapses, one trillion operations per second) developed jointly with Caltech, a factor of 100 speed-up over conventional state-of-the-art supercomputers will be achieved.
- **Demonstrated** a new Boltzmann machine architecture that obtains feasible solutions without embedding feasibility constraints on the connection matrix.
- **Demonstrated** the utility of using interactive graphics to allow experimentation and user friendliness with regard to facilitation of neural convergence and solution identification.
- **Demonstrated** the theory and algorithms relating to the determination of whether an arbitrary transition graph has a prefix code event.

## Optical Processing

- **Developed** successfully a precision Fourier optic method for characterizing electron-beam-lithographically-made Ronchi grating in Cr film on glass substrate and obtained encouraging initial results.
- **Demonstrated** successfully, for the first time, image correlation using photorefractive GaAs with two InGaAsP/InP DBF lasers, which could be a first step towards development of compact correlators as building blocks for future sophisticated object recognition systems.
- **Improved** significantly the understanding of time integration and correlation using photorefractive GaAs for RF signal processing.
- **Demonstrated** successfully the first-generation optoelectronic peak detection array chip fabricated using VLSI technology.
- **Demonstrated**, for the first time, the capability of the visible AOTF imaging spectrometer breadboard system to take high-quality video of outdoor scenes in partially cloudy days, important for future airborne and outdoor applications.
- Made significant progress to **understand** the band edge shift effect in GaAs crystal under a DC voltage due to heating under two-wave mixing condition, important for optical processing using the band edge photorefractive effect in the material.
- **Tested** successfully the capability of the first generation 32 x 32 element peak detection VLSI chips for detecting correlation peaks in an optical correlation system.

- **Demonstrated** successfully the feasibility of using degenerate four-wave mixing in photorefractive GaAs to perform time correlation and pulse compression, with potential application in RF and radar signal processing.
- **Demonstrated** excellent spatial and intensity uniformity of the image obtained by the AOTF imaging spectrometer.
- **Completed** a computer simulation to generate Mars surface contour features for investigating the hazard avoidance guidance for the Mars Lander.
- **Demonstrated**, for the first time, the capability of the IR AOTF imaging spectrometer breadboard system to measure detailed reflective spectra using a Bastnaesite sample, which are similar to those reported using a conventional precision Beckman spectrometer.
- **Demonstrated**, for the first time, a new image processing concept with attributes of optical correlator and novelty filter (e.g., moving detector), with potential applications for both detection of a moving target in a cluttered environment and recognition of the target using optical correlation using the same instrument. The demonstration experiment used a photorefractive CdTe crystal and a compact diode-pumped Nd:YAG laser in a matched filter configuration.

### Data Storage

- **Invented** a new, higher margin, read technique.
- **Verified** simulations of static behavior of domain walls.
- **Demonstrated** partial matching of bias fields to stabilize both bubble domains in the major line and stripe domains in the minor loop.
- **Demonstrated** reliable elongation of stripe domains into I/O gate (not out the opposite end).
- **Used** lift-off processing for better conductor width control. Virtually eliminated layer to layer shorts by design improvement. Improved control of garnet etching by ion implantation. Studied the variation in magnetization and coercivity of sputtered CoPt.
- **Developed** a new data structure for sequential and parallel simulations for management of the future event list called the SPEEDES Tree. This data structure outperformed the Splay Tree (normally thought of as the best data structure for this problem) by 30% or more. Because all discrete event simulations (parallel or sequential) use event lists, this achievement is very important for this field, especially in applications where the management of the event list takes a large percentage of the computation time.

### Software Engineering and Computer Science

- **Demonstrated** object-oriented classification of software components, hypermedia browsing, searching, and cataloguing tools for component databases, automatic generation of hypermedia from the database, and automatic retrieval of components over networks.

## Parallel Computation

### Publications

"Hypercube Matrix Computation Task – Research in Parallel Computational Electromagnetics, Report for 1989–1990"

T. Cwik, R. Ferraro, R. Hodges, N. Jacobi, P. Liewer, T. Lockhart, G. Lyzenga, J. Parker, J. Partee, J. Patterson and D. Simoni  
JPL Publication 91–25, January 1, 1991

"Temporal Decomposition of Simulations Under the Time Warp Operating System"

P. Reiher, S. Bellenot and D. Jefferson  
Proceedings of the 1991 Principles of Distributed Simulation Conference, p. 47–54,  
January 1991

"SPEEDES: Synchronous Parallel Environment for Emulation and Discrete Event Simulation"

J. Steinman  
Proceedings of the SCS Western Multiconference on Advances in Parallel and Distributed Simulation, vol. 23, no. 1, pp. 95–103, January 1991

"Debugging the Time Warp Operating System and Its Applications"

P. Reiher, S. Bellenot and D. Jefferson  
Proceedings of the Symposium on Experiences with Distributed and Multiprocessor Systems II, p. 203–220, March 1991

"Supercritical Speedup"

D. Jefferson and P. Reiher  
Proceedings of the 24th Annual Simulation Symposium, p. 159–168, April 1991

"Helmholtz Finite Elements Performance on Mark III and Intel iPSC/860 Hypercubes"

J.W. Parker, T. Cwik, R.D. Ferraro, P.C. Liewer, P. Lyster and J.E. Patterson  
Proceedings of the Sixth Distributed Memory Computing Conference, Portland, OR,  
April 28–May 2, 1991

"A Multicomputer Simulation of the Galileo Spacecraft Command and Data Subsystem"

J.E. Zipse, R.Y. Yeung, B.A. Zimmerman, R. Morillo, D.P. Olster, J.W. Flowe and  
T. Mizuo  
Proceedings of the Sixth Distributed Memory Computing Conference, Portland, OR,  
April 28–May 2, 1991

"Interactive SPEEDES"

J. Steinman  
Proceedings of the 24th Annual Simulation Symposium, pp. 149–158, April 1991

"An Evaluation of Fault-Tolerant Hypercube Architectures for Onboard Computing"

J.C. Peterson, J.O. Tuazon and E.T. Upchurch  
Proceedings 21st International Symposium on Fault Tolerant Computing, June 1991

"Numerical Studies of Electron Dynamics in Oblique Quasi-Perpendicular Collisionless Shock Waves"

P.C. Liewer, V.K. Decyk, J.M. Dawson and B. Lembege  
Journal of Geophysical Research, vol. 96, no. A6, June 1, 1991

"A Systolic Array Processor for Biological Information Signal Processing"

E.T. Chow, T. Hunkapiller, J.C. Peterson, B.A. Zimmerman and M.S. Waterman  
Proceedings of the 1991 International Conference on Supercomputing (ICS-91), June 17–21, 1991

"Computational Requirements for the Tropospheric Emission Spectrometer Experiment"

P.M. Lyster, L. Sparks and J.E. Patterson  
Internal Memorandum, June 1991

"Dynamic Load Balancing for a 2D Concurrent Plasma PIC Code"

R.D. Ferraro, P.C. Liewer and V.K. Decyk  
Journal of Computational Physics (submitted July 1991)

"Parallel Three-Dimensional Perspective Rendering"

P. Li and D.W. Curkendall  
Proceedings of 1992 European Workshop on Parallel Computing, March 1992 (in press)

### **Invited Presentations**

"CASA CALCRUST 3D Seismic Profiling"

L.A. Bergman  
CNRI Gigabit Testbed Workshop, Washington, DC, February 13–15, 1991

"Distributed Supercomputing for the CASA-CALCRUST Project"

P.M. Lyster  
Internet Activities Board, SDSC, La Jolla, CA, June 11, 1991

"Parallel Computational Electromagnetics"

J. Patterson, R. Ferraro and T. Cwik  
Lockheed, Burbank, CA, July 25, 1991

"Conjugate Gradient Methods Applied to Electromagnetic Scattering Problems"

R.D. Ferraro  
4th SIAM Conference on Applied Linear Algebra, Minneapolis, MN,  
September 11–14, 1991

### **Presentations**

"Temporal Decomposition of Simulations Under the Time Warp Operating System"

P. Reiher, S. Bellenot and D. Jefferson  
Proceedings of the 1991 Principles of Distributed Simulation Conference, p. 47–54,  
January 1991

"SPEEDES: Synchronous Parallel Environment for Emulation and Discrete Event Simulation"

J. Steinman

The SCS Western Multiconference on Advances in Parallel and Distributed Simulation, January 1991

"SEASCRAPE Algorithm Development"

L. Sparks

Third Tropospheric Emission Spectrometer (TES) Science Team Meeting, University of Denver, Denver, CO, March 26-28, 1991

"SEASCRAPE Requirements in a Parallel Computing Environment"

P.M. Lyster, L. Sparks and J.E. Patterson

Third Tropospheric Emission Spectrometer (TES) Science Team Meeting, University of Denver, Denver, CO, March 26-28, 1991

"Debugging the Time Warp Operating System and Its Applications"

P. Reiher, S. Bellenot and D. Jefferson

Proceedings of the Symposium on Experiences with Distributed and Multiprocessor Systems II, pp. 203-220, March 1991

"Supercritical Speedup"

D. Jefferson and P. Reiher

Proceedings of the 24th Annual Simulation Symposium, pp. 159-168, April 1991

"Interactive SPEEDES"

J. Steinman

The 24th Annual Simulation Symposium, April 1991

"Dynamic Load Balancing in a 2D PIC Code Without Particle Sorting"

R.D. Ferraro, P.C. Liewer and V.K. Decyk

The Sixth Distributed Memory Computing Conference, Portland, OR, April 28-May 2, 1991

"Helmholtz Finite Elements Performance on Mark III and Intel iPSC/860 Hypercubes"

J.W. Parker, T. Cwik, R.D. Ferraro, P.C. Liewer, P. Lyster and J.E. Patterson

The Sixth Distributed Memory Computing Conference, Portland, OR, April 28-May 2, 1991

"The Solution and Numerical Accuracy of Large Electromagnetic Problems Using the i860"

T. Cwik and J. Patterson

The Sixth Distributed Memory Computing Conference, Portland, OR, April 28-May 2, 1991

"A Multicomputer Simulation of the Galileo Spacecraft Command and Data Subsystem"

J.E. Zipse, R.Y. Yeung, B.A. Zimmerman, R. Morillo, D.P. Olster, J.W. Flower and

T. Mizuo

The Sixth Distributed Memory Computing Conference, Portland, OR, April 28-May 2, 1991

"Large Parallel Interactive Simulations"

J. Steinman and D. Curkendall

SDI Parallel Processing Group (PPG) Meeting, May 1991

"A Systolic Array Processor for Biological Information Signal Processing"  
E.T. Chow, T. Hunkapiller, J.C. Peterson, B.A. Zimmerman and M.S. Waterman  
1991 International Conference on Supercomputing (ICS-91), June 17-21, 1991

"Performance Characteristics of Large Scale Retrieval of Atmospheric Parameters in a Parallel Computing Environment"  
P.M. Lyster, L. Sparks and J.E. Patterson  
American Geophysical Union, Spring Meeting, Baltimore, MD, May 28 - June 1, 1991

"Large-Scale Retrieval of Atmospheric Parameter Profiles"  
L. Sparks, P. Lyster, J. Patterson and J. Faselow  
Physics Computing '91, Third International Conference on Computational Physics, San Jose, CA, June 10-14, 1991

"EM Scattering Computations Using Finite Elements on MIMD Computers"  
J.W. Parker, R.D. Ferraro, P.C. Liewer and P. Lyster  
Physics Computing '91, Third International Conference on Computational Physics, San Jose, CA, June 10 - 14, 1991

"A 2D Electromagnetic PIC Code for Distributed Memory Concurrent Computers"  
R.D. Ferraro and P.C. Liewer  
Physics Computing '91, San Jose, CA, June 10 - 14, 1991

"The Solution and Numerical Accuracy of Large MoM Problems"  
T. Cwik and J. Patterson  
International Union of Radio Science-IEEE Antennas and Propagation Society, London, Ontario, June 24-28, 1991

"Solving 3-D Scattering Problems with Finite Elements Using a Second-Order Local Absorbing Boundary Condition"  
J. Parker, R.D. Ferraro and P.C. Liewer  
International Union of Radio Science-IEEE Antennas and Propagation Society, London, Ontario, June 24-28, 1991

"Isoparametric Edge Elements for 3-D Electromagnetic Scattering Problems"  
J. Parker, R.D. Ferraro and P.C. Liewer  
International Union of Radio Science-IEEE Antennas and Propagation Society, London, Ontario, June 24-28, 1991

"Parallel Mesh Generation for Electromagnetic Finite Element Computations"  
R. Ferraro, J. Parker and J. Patterson  
International Union of Radio Science-IEEE Antennas and Propagation Society, London, Ontario, June 24-28, 1991

"CASA CALCRUST Parallel Rendering"  
P. Li  
The Second Gigabit Network Applications Workshop, Reston, VA, August 8, 1991

"The Event Horizon"  
J. Steinman  
Technical Information Exchange Meeting, JPL, Pasadena, CA, August 1991

"SEASCRAPE: A Large-Scale Retrieval Code"

L. Sparks

Second International Workshop, Atmospheric Science from Space Using Fourier Transform Spectrometry, JPL, Pasadena, CA, September 11–13, 1991

"Plasma PIC Simulations on MIMD Computers"

R.D. Ferraro, P.C. Liewer and V.K. Decyk

14th International Conference on the Numerical Simulation of Plasmas (APS), Annapolis, MD, September 30, 1991

"Proximity Detection"

J. Steinman and F. Wieland

SDI Parallel Processing Group (PPG) Meeting, October 1991

"Electromagnetic Scattering Using Finite Elements on a MIMD Computer"

R.D. Ferraro

Seminar, Department of Computer Science, University of Virginia, Charlottesville, VA, November 7, 1991

"The Solution and Numerical Accuracy of Large Electromagnetic Problems Using the i860 Based Parallel Supercomputer"

T. Cwik, J. Parte and J. Patterson

Supercomputing '91, Albuquerque, NM, November 18–22, 1991

"Large-Scale Retrieval of Atmospheric Parameters from Remote Sounding Data"

L. Sparks, P. Lyster, J. Patterson and J. Fanselow

Fifth Topical Meeting of Optical Remote Sensing of the Atmosphere, Williamsburg, VA, November 18–21, 1991

"High Performance Computing and Communications Program (HPCC), Earth and Space Science Applications Project (ESS)"

J. Fischer, S. Zalesak, J. Patterson, L. Hamet, J. Dorband, B. Campbell and R. Ferraro

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"Planetary Scientific Visualization – Using the Intel Delta Parallel Supercomputer"

D.W. Curkendall, P. Li and E. De Jong

The Board of Governors Meeting, JPL, Pasadena, CA, December 16, 1991

"A Network Express Demonstration of Distributed Supercomputing for the CASA-CALCRUST Project"

P.M. Lyster, L. Bergman, R. Blom, R. Crippen, L. Li, D. Okaya, C. Pard and D. Stanfill  
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"Electrostatic Particle-In-Cell Code for Hypercube Computer"

R.D. Ferraro, P.C. Liewer and V.K. Decyk

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"Synchronous Parallel System for Emulation and Discrete Event Simulation"

J. Steinman

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## **Neural and Analog Computing**

### **Publications**

"Analog VLSI Neural Networks: Implementation Issues and Examples in Optimization and Supervised Learning"

S.P. Eberhardt, R. Tawel, T.X. Brown, T. Daud and A.P. Thakoor

IEEE Trans. Industrial Electronics, A Special Issue on Neural Networks (in press)

"Non-Destructive Memory Read-out from Ferroelectric PZT Thin Films"

S. Thakoor

Trans. American Ceramic Society (in press)

"CCD Focal Plane Image Reorganization Processors for Lossless Image Compression"

S.E. Kemeny, H.H. Torbey, H.E. Meadows, R.A. Bredthauer, M.A. LaShell and

E.R. Fossum

IEEE Journal of Solid State Circuits (in press)

"Competitive Neural Architecture for Hardware Solution to the Assignment Problem"

S. Eberhardt, T. Daud, D. Kerns, T. Brown and A. Thakoor

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"A VLSI Neuroprocessor for Dynamic Assignment of Resources"

S. Eberhardt, T. Daud and A. Thakoor;

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"Electronic Neuroprocessors"

A. Thakoor

Computer Science and Electrical Engineering Department, University of Texas at Arlington, TX, September 6, 1991

"On-line Learning an Analog Neural Network Hardware"

T. Duong

Department of Electrical Engineering, UCSD, La Jolla, CA, September 13, 1991

"Neural Learning of Nonlinear Mappings: An Application in Robotics"

R. Tawel

Ascona Workshop on Industrial Applications of Neural Networks, Ascona, Switzerland, September 16-20, 1991

"Learning in Analog Neural Network Hardware"

R. Tawel

Ascona Workshop on Industrial Applications of Neural Networks, Ascona, Switzerland, September 16-20, 1991

"Integration of Neuroprocessors as Co-processors for Large Computing Platforms"

A. Thakoor

Rome Laboratory, Griffiss AFB, NY, September 17, 1991

"Neuro-computation with Analog Building Blocks"

R. Tawel

EPFL University, Laussane, Switzerland, September 23, 1991

"Electronic Neural Networks: MOSIS Experiments — What Next?"

A. Thakoor

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"Artificial Neural Networks for Image Processing"

A. Thakoor

JPL/Caltech Administration Quarterly Management Meeting, Caltech, Pasadena, CA, December 1991

"Neural Network Control of Telecommunications Switching"

T. Brown

EE class "EE 165: Topics in Telecommunications Systems Engineering" at Caltech, Pasadena, CA, May 7, 1991

"Hybrid Neural Switch Control for New Telecommunication Services"

T. Brown

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"Hardware Implementations of Fully Parallel Neural Networks"

A. Thakoor

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"Analog VLSI Implementations of Neural Network Architectures"

T. Daud

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"Photoresponse from Thin Ferroelectric Films of Lead Zirconium Titanate"

S. Thakoor

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"Slow Switching Effects in Thin Ferroelectric Films"

S. Thakoor

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"Non-Destructive Memory Read-out from Ferroelectric PZT Thin Films"

S. Thakoor

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"32 x 32 Peak Detector Array for Optical Correlator Systems"

H. Langenbacher, T. Chao, T. Shaw and J. Yu

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A.P. Thakoor, T. Daud and S.P. Eberhardt

Proc. AIAA Conference on Computers in Aerospace 8, Baltimore, MD, October 1991, p. 339. Winner of the Best Paper Award at the Conference

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S.P. Eberhardt, T. Daud, D.A. Kerns, R. Tawel and A.P. Thakoor

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"A CMOS UV-Programmable Non-Volatile Synaptic Array"

R. Tawel, R. Benson and A.P. Thakoor

IJCNN, vol. I, p. 581, 1991

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S. Kemeny et al.

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S. Thakoor

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S. Thakoor, A. Moopenn and H.L. Stadler

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A.P. Thakoor and A.W. Moopenn,  
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NASA Tech. Brief NPO-17690, vol. 14, no. 11, p. 42, 1990

"Ferroelectric/Optoelectronic Memory/Processor"  
S. Thakoor and A.P. Thakoor  
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"Porous Floating Gate Vertical MOSFET Device with Programmable Analog Memory"  
A.P. Thakoor, A.W. Moopenn and J.J. Lambe  
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- "An Unpredictable-Dynamics Approach to Neural Intelligence"  
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- "Neurodynamics with Spatial Self-Organizations"  
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- "Accuracy of CGH Encoding Schemes for Optical Data Processing"  
D. Casasent, F. Coetzee, S. Natarajan, T. Xu, D. Yu and H.K. Liu  
SPIE Proc., vol. 1555, 23–33, 1991
- "Terminal Repeller Subenergy Tunneling for Fast Global Optimization"  
B. Cetin, J. Barhen and J. Burdick  
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- "Learning a Trajectory using Adjoint Functions and Teacher Forcing"  
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### **Invited Presentations**

- "Neural Networks at NASA"  
J. Barhen  
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## **Presentations**

"Advanced Concepts in Neurocomputing"

J. Barhen

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## **Patent and New Technology Reports**

"Method and Apparatus for Second-Rank Tensor Generation"

H.K. Liu

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A. Fijany and A.K. Bejczy

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H.K. Liu

NASA Tech. Brief NPO-18009, June 19, 1989 (U.S. patent pending)

"The Optical Implementation of Inner Product Neural Associative Memory"

H.K. Liu

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"Photorefractive Crystal Compresses Dynamic Range of Images"

H.K. Liu

NASA Tech. Brief NPO-18098, vol. 15, no. 10, p. 37, October 1991 (U.S. patent pending)

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H.K. Liu

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T.H. Chao and H.K. Liu

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U. S. Patent No. 4,924,507, May 8, 1990

"Real-time Image Difference Detection Using a Polarization Rotation Spatial Light Modulator"

T.H. Chao and H.K. Liu

U. S. Patent No. 4,908,702, May 13, 1990

"Real-time Pseudo-color Density Encoding of an Image"

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## **Optical Processing**

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D.T.H. Liu and L.J. Cheng  
Opt. Eng. vol. 30, no. 571, 1991

"Optical Processing with Photorefractive Compound Semiconductors"  
L.J. Cheng, D.T.H. Liu and K.L. Luke  
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D.T.H. Liu and L.J. Cheng  
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### **Presentations**

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T.H. Chao, J. Yu, G. Reyes, D. Rider and L.J. Cheng  
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NASA Tech. Brief NPO-17768, vol. 15, no. 4, p. 54, April 1991

"High Speed Optical Processor for Photorefractive Semiconductors in Interferometric Configurations"  
L.J. Cheng and T.H. Liu  
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L.J. Cheng and T.H. Liu

NASA Tech. Brief NPO-17773, vol. 15, no. 10, p. 39, October 1991

"Optical Input, Optical Output, Morphological Processor"

L.J. Cheng, T.H. Chao and D. Psaltis

NASA Tech. Brief NPO-18174, February 5, 1990 (filed)

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L.J. Cheng, T.H. Chao and D. Psaltis

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L.J. Cheng and G.O. Gheen

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L.J. Cheng, G.O. Gheen and A. Partovi

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## **Data Storage**

### **Publications**

"Partial Grooving in Vertical Block Line Memory"

J.C. Wu, R.R. Katti and H.L. Stadler

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"Magnet-Hall Effect Random Access Memory"

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"Vertical Bloch Line Memory"

H.L. Stadler, J.C. Wu and R. Katti

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J.C. Wu, R.R. Katti and H.L. Stadler

Journal of Applied Physics, April 15, 1991

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Nonvolatile Memory Technology Review, Linthicum, MD, June 18, 1991

"Magnet-Hall Effect Random Access Memory — a Nonvolatile, High Density, High Speed RAM"

J.C. Wu

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"Magnet-Hall Effect Random Access Memory"

J.C. Wu, R.R. Katti and H.L. Stadler

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"Future Nonvolatile Memory and Storage Techniques"

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"Integrated, Nonvolatile, High Speed Analog Random Access Memory"  
R.R. Katti, H.L. Stadler and J.C. Wu  
NASA Tech. Brief NPO-17998, vol. 15, no. 11, p. 30, November 1991

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R.R. Katti, H.L. Stadler and J.C. Wu  
NASA Tech. Brief NPO-18467, January 9, 1991 (filed)

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R.R. Katti, H.L. Stadler and J.C. Wu  
NASA Tech. Brief NPO-18529, March 19, 1991 (filed)

"Three-Dimensional Magnetic Bubble Memory System"  
R.R. Katti, H.L. Stadler and J.C. Wu  
NASA Tech. Brief NPO-18533, March 27, 1991 (filed)

"New Read Gate Design for Vertical Bloch Line Memory"  
R.R. Katti, H.L. Stadler and J.C. Wu  
NASA Tech. Brief NPO-18615, July 3, 1991 (filed)

"New Memory Cell Write Design for the Micromagnet Hall Effect Random Access Memory (MHRAM)"  
R.R. Katti, H.L. Stadler and J.C. Wu  
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NASA Tech. Brief NPO-18644, July 3, 1991 (filed)

"Integrated, Nonvolatile, High Speed Analog Random Access Memory"  
R.R. Katti, H.L. Stadler and J.C. Wu  
Patent Application, 653,378, February 11, 1991 (filed)

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### **Publications**

"Object-Oriented Classification and Hypermedia for Software Reuse: Knowledge Base Overview"

B. Beckman and M. Summers

JPL Internal Document D-9422 (1991)

"The ESC: A Hypermedia Encyclopedia of Reusable Software Components"

B. Beckman, W.V. Snyder, S. Shen, J. Jupin, L.V. Warren, B. Boyd and R.C. Tausworthe  
Information Systems Prototyping and Evaluation Quarterly Report, JPL Internal Document D-8770, July 1991

### **Presentations**

"Generating Hypermedia Documents from Frame-based Data"

B. Beckman and J. Jupin

ACM SIGGRAPH '92 (filed)

"The Encyclopedia of Software Components"

B. Beckman, L.V. Warren, J. Jupin, S. Shen and R.C. Tausworthe

Video presentation; abstract in Proceedings of ACM Hypertext '91, Austin TX, December 1991

### **Patent and New Technology Reports**

"Encyclopedia of Software Components (ESC)"

L. Van Warren and B. Beckman

NASA case no. NPO-18435-1-CU (patent pending)



## IV. Custom Microcircuits



## Overview

The goals of this program are to develop custom microcircuit technology, also known as Application Specific Integrated Circuit (ASIC) technology, for use in flight and ground programs. Supporting this effort are activities to investigate the effects of the space environment, and particularly ionizing radiation, on microcircuits and to develop a space qualification methodology. Another aspect of the program emphasizes innovative applications of custom microcircuit technology to image and signal processing and communications.

## 1991 Major Technical Achievements

- **Designed and fabricated** a VLSI chip set for an advanced spaceborne computer. The computer features a 16 bit data path based on Sandia's SA3300 Rad board, SEU resistant microprocessor, which executes the National Semiconductor NSC32016 instruction set. These custom chips for the computer were designed and fabricated by JPL: Direct memory access coprocessor (DMAC); fault management unit (FMU); control unit (CU); floating point unit (FPU) (joint project with Sandia).
- **Designed** three complex custom microcircuits with JPL Standard Cell Library and fabricated at US2 foundry. These circuits are three of six chips required for proposed single-board Spacebourne Advanced Computing Engine or SPACE16 capable of supporting science applications aboard EOS and other spacecraft. Breadboard is now in procurement.
- **Identified** failure mechanisms for Schottky gate GaAs ICs. Test structures were designed to characterize these mechanisms. A test chip was designed containing these test structures (over 60 test structures) for Vitesse HgAs II technology. The test chip layout was submitted to Vitesse and was fabricated on a dedicated run.
- **Developed** an advanced reliability test system with high throughput capability. This system is being implemented.
- **Configured** a parametric tester comprising HP4062 hardware and the IC-CAP and ICMS data acquisition software.

## Custom Microcircuits

### Publications

"Real-Time Computing of Optical Flow Using Adaptive VLSI Neuroprocessors"

W.-C. Fang and B.J. Sheu

IEEE International Conference of Computer Design, Cambridge, MA, October 1990

"Test SRAMs for Characterizing Alpha Particle Tracks in CMOS/Bulk Memories"

M.G. Buehler, B.R. Blaes and G.A. Soli

Proc. IEEE 1991 Int. Conference on Microelectronic Test Structures, vol. 4, no. 1, March 1991

"The Inverter Matrix: A Vehicle for Assessing Process Quality Through Inverter Parameter Analysis of Variance"

B.J. Hannaman, M.G. Buehler, J. Chang and H.R. Sayah

Proc. IEEE 1991 Int. Conference on Microelectronic Test Structures, vol. 4, no. 1, March 1991

"VLSI Adaptive Image Compression"

W.-C. Fang and B.J. Sheu

Advanced Research in VLSI Conference 1991, Santa Cruz, CA, March 25-27, 1991

"A Neural Network Based VLSI Vector Quantizer for Real-Time Image Compression"

W.-C. Fang, B.J. Sheu and O.T. Chen

IEEE Data Compression Conference, Snowbird UT, April 7-11, 1991

"A Very High Speed Lossless Data Compressor Chip for Space Imaging Applications"

R. Anderson, J. Bowers, W.-C. Fang, D. Johnson, J. Le and R. Nixon

IEEE Data Compression Conference, Snowbird, UT, April 7-11, 1991

"Real-Time High-Ratio Image Compression Using Adaptive VLSI Neuroprocessors"

B.J. Sheu and W.-C. Fang

IEEE 1991 International Conference on Acoustics, Speech and Signal Processing, Toronto, Ontario, Canada, May 14-17, 1991

"A Neuroprocessor for Real-Time Image Flow Computation"

W.-C. Fang, B.J. Sheu and J.C. Lee

IEEE 1991 International Conference on Acoustics, Speech and Signal Processing, Toronto, Ontario, Canada, May 14-17, 1991

"A Real-Time VLSI Neuroprocessor for Adaptive Image Compression Based Upon Frequency-Sensitive Competitive Learning"

W.-C. Fang, B.J. Sheu and O.T. Chen

International Joint Conference on Neural Networks, Seattle, WA, July 9-12, 1991

"Systolic Tree-Searched Vector Quantizer for Real-Time Image Compression"

W.-C. Fang, C.-Y. Chang and B.J. Sheu

VLSI Signal Processing, IV, edited by H. Moscovitz, K. Yao, R. Jain, IEEE Press, 1991

"Bench-Level Characterization of a CMOS Standard-Cell D-Latch Using Alpha-Particle Sensitive Test Circuits"

B.R. Blaes, G.A. Soli and M.G. Buehler

IEEE Transactions on Nuclear Science, December 1991 (in press)

"CRRES Microelectronic Test Chip"

Y-S Lin, M.G. Buehler, K.P. Ray and M.M. Sokoloski

IEEE Transactions on Nuclear Science, December 1991 (in press)

### **Presentations**

"GaAs Reliability"

N. Zamani

DARPA Digital GaAs Insertion Workshop, Reston, VA, April 25, 1991

"GaAs Reliability"

N. Zamani

DARPA Digital GaAs Insertion Workshop, Reston, VA, October 24, 1991

### **Patent and New Technology Reports**

"Five-Segment Interconnection for Electromigration Tests"

D. Hannaman and M. Buehler

NASA Tech. Brief NPO-18105, vol. 15, no. 8, p. 18, August 1991

"Cross-Quint-Bridge Resistor"

D. Hannaman, M. Buehler, U. Lieneweg and L. Mantalas

NASA Tech. Brief NPO-18106, vol. 15, no. 6, p. 28, June 1991



## V. Appendix

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## CSMT-Caltech Campus Collaborations

H. Atwater	In situ electron energy loss characterization of MBE growth technology
A. Awaal	Spatial light modulators
J. D. Baldeschwieler	Scanning tunneling microscopy research
J. Bower	Neural oscillations in cognitive neuroscience
J. Burdick	New methods for global optimization with application to redundant robots operating in unstructured environments
F. Culick	
T. Gottschalk	Concurrent multi-target-tracking
R.H. Grubbs	Nonlinear optical polymers
K. Huang	Super computing algorithms & architecture
M. Karim	Spatial light modulators & neural computation
J.B. Lathrop	Parallel universe and concurrent computation in C++
N. Lewis	Surface passivation and electrochemistry of III-V compound semiconductor
V.M. Lubecke	Adjustable RF tuning elements
V. McKoy	Diamond film technology
T.G. Phillips	Development and fabrication SIS mixers for the Caltech Submillimeter Observatory (CSO)
J. Pine	Micromachining technology
	Neuron culture and electronics development
D. Psaltis	Optoelectronically implemented neural network architecture
B.D. Rutledge	Adjustable RF tuning elements
	Millimeter-wave imaging arrays
W.P. Schaefer	Crystal structures of organic nonlinear optical materials
N. Scoville	SIS mixers with improved rf and IF characteristics for the Owens Valley Radio Observatory (OVRO)
D.P. Woody	
Y.C. Tai	Micromachining technology
	Test chip development for in-vitro testing
	Caltech micromachined optical components
K. Valhala	Selective-area patterned growth by MOCVD

D. Wertekamp

Solid state NMR spectroscopy of hole and electron gases at semiconductor quantum wells

J. Wu

Neural network & optical computing

A. Yariv

Large-scale processors and algorithms for neurocomputing and signal analysis based on CCD technology

N.C. Yeh

High T<sub>c</sub> superconductivity

S.M. Zhou

Optical computing & spatial light modulators

J.X. Zmuidzinas

Development of Josephson effect array oscillators and novel receiver designs

## CSMT — Other Collaborations

S. Ali (Massachusetts Institute of Technology)	Mixer analysis
D. Andes (Naval Weapons Center, China Lake, CA)	Development of neurocomputing methods for target detection in cluttered background using VLSI analog neuroprocessors
P. Bhattacharya, (University of Michigan)	Data storage
S. Bellenot (Florida State University)	Time Warp Simulation Technology Development Task
A.A. Bhatti (Memphis State University)	Neural and analog computing
R.A. Buhrman (Cornell University)	Tunnel barrier noise properties
G. Buzaki (Rutgers-The State University, NJ)	In-vivo testing and histology of rat hippocampi
D. Casasent (Carnegie-Mellon University)	Computer generated holograms & optical processing
L.T. Cheng (Dupont Co.)	Hyperpolarizabilities of organics and organometallics
T. Crowe	Planar diodes
R.J. Mattauch (University of Virginia)	
N. Dagli (University of California, Santa Barbara)	Electron waveguides
L.C. Davis (Ford Research Staff, Ford Motor Co.)	BEEM research
V. K. Decyk (University of California, Los Angeles)	Particle Simulations
B. Dunn (University of California, Los Angeles)	Sol-Gel nonlinear optical materials
J. East (University of Michigan)	Submillimeter-wave mixer analysis
N. Erickson (University of Massachusetts)	Submillimeter-wave multipliers
J. Essick (Occidental College)	Photovoltaic technology
D. Fransen (National Institute of Standards and Technology)	Erbium fiber ring mode-locking
T.K. Gaylord (Georgia Institute of Technology)	BEEM research
J. Green (University of Oxford)	Synthesis of organic and organometallic NLO materials
A. Grimshaw (University of Virginia)	Object-oriented Parallel Programming Paradigms

J. Heritage (University of California, Davis)	Ultra-fast fiber pulse transmission
G. Hower (Naval Weapons Center, China Lake, CA)	Fiber optically guided missiles
R. Iltis (University of California, Santa Barbara)	Neural and analog computing
D. Jefferson (University of California, Los Angeles)	Time Warp Simulation Technology Development Task
P. Kaaret (Columbia University)	Micromachined X-ray optical components
E. Kollberg (Chalmers University, Sweden)	Submillimeter wave varactors
N. Luhmann (University of California, Los Angeles)	Millimeter-wave imaging arrays
A. Madhuhar (University of Southern California)	MBE growth and characterization of lattice mismatched devices on patterned substrates
R. McNaughton (Rensselaer Polytechnic Institute)	Counter Free Automata
R. Mittra S. Gedney (University of Illinois)	Parallel Computational Electromagnetics
D. Okaya (University of Southern California)	CALCRUST seismic data preparation
S. Reich (McDonnell Douglas Corp.)	Space station fiber packaging
D. Rich (University of Southern California)	Cathodoluminescence and neuro-optical characterization of semiconductor heterojunctions and nanostructures
Rockwell International Science Center	First demonstration of a hybrid HIP detector array bump bonded to readout electronics
J. Sauer (University of Colorado)	Hot potato fiber network
L. Schowalter (Rensselaer Polytechnic University)	Device transport and ballistic electron emission microscopy (BEEM) measurements
J. Simpson (American Telephone and Telegraph Co.)	Custom doped erbium fiber
E. Soloway (University of Michigan)	Empirical observations of programmer behavior
E. Van Stryland (University of Central Florida)	Passive optical limiters, nonlinear optics of phthalocyanines
A. Stubberud (University of California, Irvine)	Neural and analog computing
A. Tanielian (Revtek Corp.)	Data storage
S. Velsko (Lawrence Livermore National Laboratory)	Nonlinear optics of bio-organic crystals

A. Weiner (Bellcore, Bell Communications Research, Inc.)	CDMA phase mask fabrication
I. Williams (Pennsylvania State University)	Nonlinear optics of bio-organic crystals
D. Williamson (Colorado School of Mines)	Photovoltaic technology
J. Woodall (International Business Machine Corp., Watson Research Laboratory)	Strained layer high electron and hole mobility transistors
C. Yakymyshyn (General Electric Co.)	Electro-optic organic salt crystals
W. Yamada, K. MacWilliams (Aerospace Corp.)	GaAs Reliability
P. Yeh (University of California, Santa Barbara)	Nonlinear wave interactions and optical computing

## **Distinguished Visiting Scientists**

- Professor Ravindra Althale, Department of Electrical Engineering and Computer Science, George Mason University
  - Optical processing and neural networks
- Professor Francis T.S. Yu, Department of Electrical Engineering, Pennsylvania State University
  - Optical processing and optical fiber sensors
- Professor L. Eric Cross, Department of Electrical Engineering, Pennsylvania State University
  - Chaired Professor
  - Former Director of Materials Research Laboratory
  - Member of National Academy of Engineering
  - Piezoelectric and Ferroelectric Materials
  - Director of the Center for Electro-Optic Research
  - Optical Fiber Sensors and Optical Neural Networks
- Professor Floyd B. Humphrey, Department of Electrical Engineering, Boston University
  - Former Professor, Caltech; Chairman of Electrical Engineering and Professor, Carnegie-Mellon University
  - Led development of the Permanent Magnet Twistor Memory
  - Originated Vertical Bloch Line (VBL) Memory development in the United States
  - Fellow, IEEE
  - 1988 Achievement Award of the IEEE Magnetics Society
  - IEEE, outstanding lecturer 1973 to 1977
  - General Chairman, 1972 Intermag Conference
- Dr. Heinrich Rohrer
  - Nobel Laureate 1986
  - Inventor of scanning tunneling microscopy
- Professor M.G. Spencer, Howard University
  - MBE of High Electronic Mobility Devices
  - Laser assisted Molecular Beam Epitaxy

## **Honors and Awards**

W.J. Kaiser

Peter Mark Award

M.H. Hecht

Lew Allen Award, semiconductor surface photovoltaic effects

A.P. Thakoor

Thomas R. Benedict Memorial Award

## **Conferences and Workshops Sponsored and/or Hosted by CSMT**

Sensor Systems for Space Astrophysics in the 21st Century, Pasadena, California (January 23–25, 1991)

BEEM Workshop '91, Pasadena, California (January 28, 1991)

Second International Symposium on Space Terahertz Technology (March 1991)

SDIO/IST and NTB Computer Networking Workshop (June 1991)

Symposium on Nanostructure and Applications (November 19–20, 1991)